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Science and Technology Collaboration: Building Capacity in Developing Countries

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Contents

Preface	i
Figures	v
Tables	vii
Summary	ix
Measuring Scientific Capacity	x
Collaborations that Build Capacity	xi
Patterns and Linkages in International Collaboration.....	xii
Reasons for Collaboration	xiii
The Role of Information and Communications Technologies in Collaboration.....	xiv
Observations and Recommendations	xv
Acknowledgments	xvii
Abbreviations.....	xix
Introduction and Background: Science, Technology, and Development	1
What are the Linkages Between Science, Technology, and Development?	2
Methodology Used for this Study	6
Organization of this Report.....	7
S&T Capacity Across Countries	9
Developing an Index of S&T Capacity	10
Scientifically Advanced Countries.....	11
Scientifically Proficient Countries.....	12
Scientifically Developing Countries.....	14
Scientifically Lagging Countries.....	15
Limitations of this Approach	17
Collaboration between Advanced and Developing Countries	19
Estimating Spending.....	19
Examining Co-authorship Patterns.....	23
Explanation of Diagrams in the Following Sections.....	25
Regional Patterns of Collaborative Links.....	26
Commonwealth of Independent States (CIS) and Balkan Region	26
Asia.....	27
Middle East and Africa.....	29
Latin America	30
Scientific Capacity and Collaborative Links	33
Advanced Country Connections with Proficient and Developing Countries	33
Linkages Between Proficient and Developing Countries	37
Trends in Publication Patterns.....	38

Motivations for Collaboration Go Beyond Scientific Compatibility and Complementarity.....	41
Movements of People	42
Limitations of this Approach	43
Collaboration Is Building Capacity – Results of Conversations with	
Scientists	45
Methodology	45
Collaboration is Building Capacity	46
Collaboration is Building Independent Capacity.....	47
Nature of Research Affects Motivations for Collaboration.....	48
Collaboration as a Scientific Imperative.....	49
Collaboration as an Added Benefit.....	51
Perceived Costs and Benefits	53
Initiation of Activities is Often Mutual.....	55
Frustrations of Collaborating	55
The Role of Information and Communications Technology.....	56
Limitations of this Approach	58
Increasing the Effectiveness of Future Efforts	61
Future areas of study	64
Appendix A: Data supporting the Composite S&T capacity index	65
Appendix B: Report on Interviews with Scientists	71
Bibliography.....	85

Figures

Figure 2.1: Scientifically Advanced Countries on an S&T Composite Index	12
Figure 2.2: Scientifically Proficient Countries on an S&T Composite Index	13
Figure 2.3: Scientifically Developing Countries on an S&T Composite Index	14
Figure 2.4: Scientifically Lagging Countries (1) on an S&T Composite Index	15
Figure 2.5: Scientifically Lagging Countries (2) on an S&T Composite Index	16
Figure 2.6: Scientifically Lagging Countries (3) on an S&T Composite Index	17
Figure 3.1: Graphical Explanation of the Country-Country Linkages Pictured in the Subsequent Figures	26
Figure 3.2: Patterns of Co-authorship in the CIS and Balkan Region.....	27
Figure 3.3: Patterns Of Co-authorship in Asia	28
Figure 3.4: Patterns of International Co-authorship in the Middle East and Africa.....	30
Figure 3.5: Patterns of Co-authorship in Latin America	31
Figure 3.6: Patterns of Co-authorship Between Scientifically Advanced and Proficient Countries	34
Figure 3.7: Patterns of Co-authorship between Scientifically Advanced and Developing Countries.....	35
Figure 3.8: Patterns of Co-authorship Between SACs and SLCs	36
Figure 3.9: Patterns of Co-authorship between Proficient, Developing, and Lagging Countries.....	38
Figure 4.1: Internet Access for Different Parts of the World	57

Tables

Table 3.1: Estimates of Single Year Spending for Collaboration, Research-for-Aid, and Total Official Development Assistance by Key Countries	21
Table 3.2: The Relationship between the Number of Scientifically Lagging Countries in a Region and the Number of Collaborative Linkages.....	31
Table 3.3: Increases and Decreases in Co-authorships between Advanced Countries with Proficient, Developing, and Lagging Countries: 1986-88 to 1995-97	39
Table 4.1: Percentage of Respondents Mentioning Local "Natural" Resources as Important for Research Collaboration	50
Table 4.2: Percentages of Respondents in a Field Citing Expertise, Facilities, or Equipment as a Reason for Collaboration.....	52
Table 4.3: Motivation for Collaboration Cited (by Country Type of the Collaborating Nation).....	53
Table 4.4: Did the Collaboration Increase the Scientific Capacity of your U.S. Institution? (by Country Type of Collaboration)	54

Summary

International collaboration is replacing other models as the preferred method of building scientific capacity in developing countries and it appears to be producing results. Researchers from scientifically advanced countries collaborating with developing country counterparts report that these activities are building international-level scientific capacity in those countries. Indicators show that the amount of collaborative research between advanced and developing country scientists is rising. The number of scientific papers published between scientists from these countries has been rising as well.

International scientific collaboration—where scientists work with their counterparts in other countries towards a common research goal—is growing as a percentage of all scientific activity. Researchers from developing countries are taking part in and benefiting from this activity. International collaboration takes a number of forms, including sharing of research data, joint experimentation, conferences and other meetings, building of databases, standards-setting, and equipment sharing. A research problem that spans the globe, such as global climate change or infectious disease control, can be one of the primary motivating forces behind international collaboration, followed by the location of specific resources, unique expertise, and the location of large-scale equipment.

Policymakers and economists continue to see science and technology as an engine of economic growth. In advanced industrialized countries, S&T has been shown to contribute significantly to economic growth and productivity enhancement. Economists have yet to demonstrate the same concentration of benefit for developing countries. Despite the lack of a theoretical or quantitative link between S&T investment and development in developing or underdeveloped countries, many policymakers assume that benefits will accrue from such investments. Specific cases where this has occurred, starting with Japan and more recently experienced in South Korea, India, and Brazil, suggest that S&T investments can help economic growth. Until better economic and organizational research can be done, however, the assumption of a positive relationship, based on observation, serves as the basis for discussion in this report.

Measuring Scientific Capacity

While collaboration among developed and developing countries were once referred to as "North-South" or "donor-host" relationships, regional groupings or unequal partnerships no longer adequately describe global relationships in S&T. Distributed growth over the past 15 years in S&T investment and infrastructure has resulted in more and broader excellence in science. Scientific capacity—the infrastructure, investment, institutional and regulatory framework, and personnel available to conduct scientific research and technological development—derives from historical patterns and political and economic priorities. However, where it was once limited to a few wealthy countries, scientific capacity can now be found in more than 50 countries of the world.

The following terms are used in this report to better represent the players involved in international science based on an index developed for this study to characterize national S&T investment and output:

- A. "Scientifically advanced countries" (SAC) - the 22 countries with scientific capacity well above the international mean;¹
- B. "Scientifically proficient countries" (SPC) - the 24 countries which also have positive standing in scientific capacity when compared to the rest of the world;
- C. "Scientifically developing countries" (SDC) - the 24 countries with some features of scientific capacity, and where the trend in spending is positive but whose scientific capacity is below the international mean;
- D. "Scientifically lagging countries" (SLC) - the 80 countries with little data indicating scientific capacity.

The scientifically advanced countries account for between 90 and 95 percent of all research and development spending, an estimated \$450 billion per year, including both publicly and privately funded research and development (R&D).² Although there have been small increases in the percentage of R&D spending in developing countries, estimates made in the 1990s indicated that those expenditures may be decreasing (Salomon et al., 1994).

¹ The international mean was determined by averaging all of the data gathered for a given variable (e.g., scientists and engineers). These values were combined into a single index by comparing each country to the world average for each variable.

² All dollar figures are in US dollars unless otherwise stated.

Although legal boundaries are a ready method of classification, relying on nation-states as a grouping for scientific activity does not represent the whole picture. Often, a world-class capability exists in what would otherwise be called a developing country. An example cited by scientists with whom we spoke is mathematics research in India, which is considered among the best in the world. Other examples are China, which does world-class seismology research, the Philippines, which is an international leader in rice research, and Chile, which has developed strength in astronomy. In these cases, expertise grows out of deliberate government policies to support S&T capacity building, actions by international development organizations, the unique geography, ecology, history, or social conditions in a country, or the presence of special research equipment and laboratories. An examination of fields of specialization shows that the position of a country on a list of scientifically developing or lagging countries does not always reflect these pockets of excellence.

Scientists from scientifically developing and lagging countries often work and study in the scientifically advanced countries. The links established between scientists create connections that often result in contact over many years' time. Moreover, scientists from SDCs and SLCs working in advanced countries do not necessarily represent a net "brain drain." Often these scientists retain close ties with laboratories in their countries of origin, help to channel resources there, and frequently train young scientists from their home country. While a large percentage of these scientists choose to reside in an advanced country, for some countries an increasing number return home to establish labs or otherwise enrich existing scientific research (NSF, 2000).

Collaborations that Build Capacity

SACs spend a portion of their budgets on international collaboration. This ranges from 5 percent for the U.S.,³ which is the lowest among advanced industrial economies, to perhaps as much as 25 percent in the case of smaller, advanced economies. These funds are allocated in a "bottom-up" peer-reviewed process, with funds granted to scientifically excellent research, regardless of the partnering arrangements made by national scientists. As such, these types of collaborations differ from spending dedicated to foreign research-for-aid

³ See Caroline Wagner, "International Cooperation in Research and Development: An Inventory of U.S. Government Spending and Framework for Measuring Benefits," RAND, 1997 and Caroline Wagner et al., "International Cooperation in Research and Development: An Update to an Inventory of U.S. Government Spending," RAND, 2000.

programs, which tend to be "top-down" in their mission focus and allocation. Total spending on research-for-aid has been estimated by others to be approximately \$865 million a year for a subset of the major donor countries.⁴ Funds dedicated to collaborative research between SACs and SPCs or SDCs appears to be about \$1.4 billion per year. Very little is spent on collaboration with scientifically lagging countries; most projects mentioning an SLC is research *about*, rather than *with*, the country.⁵

Of the scientifically advanced countries spending R&D funds on collaborations with or about SDCs and SLCs, the United States is the largest in gross expenditures, at about \$600 million per year. (Table 3.1 in the body of the report provides details.) The European Community reports that they spend about 5 percent of their public funds or approximately \$122 million per year on research with developing and lagging countries outside of the European Union. The European Free Trade Association countries spend the highest proportion on collaborations with scientifically developing and lagging countries, although the majority of these efforts would be considered in the "research-for-aid" or ODA category rather than being true collaboration. Japan, too, commits public funds for these types of collaborations, with an emphasis on engineering and standards-setting projects.

Patterns and Linkages in International Collaboration

The increasing number of linkages between researchers in scientifically advanced and developing countries is reflected in the number of papers co-authored across national borders. Co-authored scientific papers including authors from SACs and SDCs are growing, although not as quickly as comparable trends among SACs. In general, we find that scientists in advanced countries are most likely to collaborate with those in other advanced nations. However, this number includes scientists originally from scientifically developing and lagging countries who work or study in advanced nations.

⁴ This value represents a subset of estimates made by Gaillard from data on the 1980's. When activities by major international organizations are included, this value increases to approximately \$2 billion. It should be emphasized that the data which serve as the basis for these estimates are very weak. This value was based on surveys of aid organizations which was then scaled by various factors to account for other groups that were not queried and adjusted for an assumed increase in support over time.

⁵ These values are a subset of total official development assistance which, in 1997, totaled nearly \$49 billion for the top 15 donor nations.

Patterns of cooperation do not change quickly, as shown by Okubo and others in previous studies. Scientifically advanced countries share similar research profiles that stimulate collaboration among them, and these countries collaborate in all major scientific fields. Developing and lagging countries, in contrast, are more likely to specialize in a few areas of science, often in fields that relate directly to some national need, like disease control. Among new scientifically advanced countries, such as South Korea, the patterns of cooperation still look like those of developing nations-the majority of their international collaborations are with other SACs, rather than extending to scientifically developing and proficient countries.

In addition to active collaboration among themselves, advanced countries are increasingly collaborating and co-publishing with scientists in scientifically proficient and developing countries. Data show an increasing number of collaborations between scientists in SACs with their counterparts in SPCs and SDCs. Most scientifically, proficient and developing countries listed in the S&T composite index have significant linkages (greater than 8 percent of their collaborative publications per year) with advanced countries.

Scientifically advanced countries have little interaction with scientifically lagging countries. Moreover, we observed a drop in the number of papers resulting from collaborations between scientifically advanced and lagging countries compared with those of proficient and developing countries. However, our research shows that, at least for the United States, as much as \$50 million per year is being spent by the U.S. government on research about conditions or resources in scientifically lagging countries. The fact that collaborations have not emerged around these studies may indicate that local scientists are not able or available to work on these subjects. This analysis must be understood in context: the data on scientifically lagging countries are sparse.

Scientifically proficient and developing countries are increasingly likely to collaborate with each other. Although not at the same levels of scientific capacity, proficient and developing countries share similar features promoting collaboration.

Reasons for Collaboration

Scientists are likely to collaborate with their international counterparts for reasons that go beyond scientific compatibility and complementarity. Among these factors are the following:

- **Geographic proximity:** Neighboring countries often have similar research or complementary interests and common publication profiles;
- **History:** Ties that form human, linguistic or other ties, as a result of historical interactions (including colonial relationships) support present-day collaborations;
- **Common language:** A shared language facilitates collaboration;
- **Specific problems and issues:** Common problems, such as disease control or natural disaster mitigation;
- **Economic factors:** Factors include investment in a particular field because of research priorities set by scientists and policymakers, individual scientists collaborating with particular universities, and the need to share facilities and equipment;
- **Expertise:** Collaborations can be driven by the need for the best, or most appropriate, expertise to pursue the objectives of the scientific query. Many developing countries have institutions and individuals with world-class expertise; and
- **Research equipment, databases, and laboratories:** The presence of particular research equipment, databases, and laboratories in a country can give rise to international collaboration.

When scientific motives drive the research, scientists report that shared interest in the research problem is the leading reason for collaboration. Interviews showed, for example, that the majority of the projects we examined were initiated jointly by principal investigators from both the United States and the foreign country. In the majority of these cases, respondents reported that the foreign partner possesses expertise relevant and important to their research problems. The collaborations were most often built on common and complementary experiments and data exchange.

The Role of Information and Communications Technologies in Collaboration

Scientists reported that information and communications technologies have been highly influential, although not decisive, in encouraging international collaborations. Most scientists reported that they began their collaborations as a result of meeting in person either at a research site or at an international

conference. After their initial face-to-face meeting, scientists used the full range of information technologies to continue formal or informal collaboration.

When asked about the medium for exchanging information, scientists told us that the Internet has become the central mechanism for communication and information exchange. Over three-fourths of the scientists with whom we spoke reported using the Internet for electronic mail, transfer of data files and exchange of other digital documents when collaborating with developing country counterparts. The proliferation of Internet access in developing countries has helped to cut costs and reduce time spent in communication and information exchange. Telephone calls, facsimiles and postal or courier services have become secondary to the Internet, scientists told us.

Although many respondents said that the Internet has revolutionized communication and information exchange in international collaborations, they also stressed its limitations. First, the majority felt that the Internet does not substitute for face-to-face interaction to discuss ideas or work on experiments. Some emphasized that personal interaction helps to build trust and confidence, which are critical to forming collaborations and making them successful. Personal interaction also is key to many capacity-building activities that require the learning of physical skills and exchange of tacit knowledge.

Observations and Recommendations

In many of the cases we examined, collaboration is having a positive impact on capacity building. Nevertheless, S&T capacity building does not automatically result from these activities. A few respondents questioned the relevance of knowledge created or S&T capacity built as a result of international collaboration to the needs of developing countries. In some cases, the topics of joint research depended upon the interests of the advanced country, and developing country scientists sometimes pick research problems that have more appeal to international partners than any real value to their own country. Developing country scientists may also be motivated to participate in international collaboration with advanced country researchers in order to raise their status and influence in domestic science and policy circles.

Research that is most likely to build capacity arises out of complementary research interests of the participating scientists. Scientists and analysts report that the shared project should be of interest to both participating countries with both sides contributing something (expertise, equipment, data bases, etc.) to the endeavor. Both sides should have control over or say in how the budget is

allocated and spent. A limited number of sponsors for any research project—meaning adequate funding from one or two agencies—helps to reduce the amount of time needed to fill out applications or account for activities and outcomes. If possible, proposals should be drafted jointly, and any decision about the purchase of instrumentation should be made jointly. Provisions should be made for equipment installation, maintenance and repair. Information and communication technologies should be used to ensure transparency of activities and continuous updates on progress. Metrics should be determined ahead of time, built into the proposal, accounted for by all teams, and collected regularly by all parties to ensure objective evaluation and feedback into the ongoing process. Finally, the presence of a few passionate leaders and/or champions can positively affect the success of international S&T collaboration. Studies have shown that these individuals can play key roles in recruiting the necessary resources and expertise to launch and sustain projects.⁶

Although the majority of collaborative S&T funds are spent between the SACs and SDCs, there is a growing amount of research about SLCs that represents a potential pathway to increasing collaboration. To the extent that scientists can use these lines of inquiry to actively seek partners in developing countries, this may help build capacity in these nations. In addition, if SLCs can take advantage of the interest of scientists from SACs and SDCs to build databases or infrastructure, this also may be a stepping stone towards capacity development.

The scientific questions or nature of research experimentation will influence collaboration and should be considered during the planning of any joint efforts as well as in the assessment of their success. Whether a science is observational (plant study), experimental (clinical medicine) or theoretical (mathematics) will influence the scale, scope, and content of joint research. Some areas of observational and theoretical science, because they require less costly equipment or facilities, are easier to fund and can more readily be made the subject of international collaboration. The nature of the research (global, shared expertise, equipment based), combined with an understanding of the three kinds of projects identified in the course of our research, should be considered when thinking about support for collaborative research.

⁶ Observations of this were made by a recent RAND study on lessons learned in international S&T cooperation and a study on S&T cooperation among industrialized countries completed by the National Research Council, "Scientific and Technological Cooperation Among Industrialized Countries: The Role of the U.S.," 1984.

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Abbreviations

Abbreviation	Word or Phrase
CERN	European Consortium for Nuclear Research
CIS	Commonwealth of Independent States
EC	European Community
EFTA	European Free Trade Association
EU	European Union
EPO	European Patent Office
GERD	Gross Domestic Expenditure on Research and Development
GNP	Gross National Product
GPS	Global Positioning System
ICST	International Collaboration in Science & Technology
ICT	Information and Communications Technologies
IDRC	International Development Research Centre
ILL	Institute Laue-Langevin
IPR	Intellectual Property Rights
ISC	International Scientific Cooperation Scheme
MECU	Millions of European Currency Units
NSB	National Science Board
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
ODA	Overseas Development Assistance

Abbreviation	Word or Phrase
PPP	Purchasing Power Parity
PI	Principal Investigator
SAC	Scientifically Advanced Country
SDC	Scientifically Developing Country
SLC	Scientifically Lagging Country
SPC	Scientifically Proficient Country
S&T	Science and Technology
STD	Science and Technology Development Program
R&D	Research and Development
USAID	U.S. Agency for International Development
USPTO	United States Patent and Trademark Office

Introduction and Background: Science, Technology, and Development

This report presents research and analysis of existing data and literature to address three questions about science, technology, and development:

- The extent to which funds from the wealthiest science and technology (S&T) performing countries are supporting collaboration in or with the developing world;⁷
- The extent to which this funding is actually building S&T capacity in developing countries; and
- The trends in S&T collaboration (including those resulting from increased use of information and communications technologies (ICT)) between the developed and developing world and the implications of those activities for the S&T capacity of developing nations.

The question of whether merit-based collaboration builds scientific capacity has received little attention in the past. Existing literature has addressed either:

- Collaboration among scientifically advanced nations, focusing on the nature and extent of "bottom-up" peer contacts (Wagner, 1997; Georghiou, 1998; Stein, 1999); or
- What has been called "research aid for development" or "capacity building"—those activities funded by the scientifically advanced nations to help scientifically developing and lagging nations to either address specific problems or increase scientific capabilities. The focus of these studies has been on "top-down" aid, and only secondarily, and perhaps not at all, on the extent to which linkages between developed and developing countries are peer-based scientific research (Lewis, 1987; Institute of Development Studies, 2000; Gaillard, 1994).

⁷ There is no definitive definition for the term "developing country." The term is sometimes used in reference to countries with a gross domestic product per capita below a certain rate, say \$10,000, or as countries that do not yet belong to the Organisation for Economic Cooperation and Development (OECD).

The two lines of analysis have had little intersection, and indeed, the activities of these two communities have little in common. Merit-based science is by definition aimed at creating excellent science no matter where in the world it is being conducted; research aid for development focuses primarily on building capacity and only secondarily is consideration given to whether excellent science is being funded.

Nevertheless, the intersection of collaboration and capacity building is now an important area for examination. Data show increasing merit-based collaboration between developed and developing countries over the past 15 years. In addition, a number of emerging global and transboundary problems (infectious disease control, global climate change) require international cooperation; in cases where capacity is lagging, it is often in the interest of the developed world to help build it. There is also a growing view that research aid for development has not been effective in building capacity and therefore is a policy in need of change.

Moreover, during the past 15 years, for a number of complex and self-reinforcing reasons, many countries that were once lagging in science have become scientifically proficient or even advanced. Scientists in, for example, Korea, Mexico, Argentina, Chile, and India, at least in some areas of science, are publishing world-class papers in scientific journals at the highest levels of scientific discourse. As the number of nations participating in the international scientific community has grown, so has the complexity of the linkages among them. Many countries encourage their scientists to collaborate internationally. These collaborations in turn help to build scientific capacity, creating a virtuous cycle. The extent to which this positive link between collaboration and scientific development can be designedly reproduced in other places remains to be seen. This report attempts to contribute to this discussion by better characterizing S&T collaboration between advanced and developing countries in order to identify where and how interventions may help to reinforce or initiate this process.

What are the Linkages Between Science, Technology, and Development?

Many development experts and policymakers increasingly see investment in science and technology as a key contributor to economic growth and the development of a market-based economy. Economists have made various attempts to characterize the benefits and to quantitatively link S&T capacity to economic growth. Three approaches that are most often used and cited are:

- Input/output models describing the relationship between R&D inputs and such outcomes as changes in the value added, net profits, output, or rate of economic growth. Data have been collected at various points within the economy, from the firm level to industries, economic regions, or national economies. Robert Solow produced some of the early work combining growth accounting with research on the rate of technological change applied to the U.S. economy in the first half of the twentieth century. Solow concluded that a residual or unexplained portion of U.S. economic growth stemmed from technological advances and that this residual far outweighed changes in capital or labor.
- Total factor productivity or growth accounting analysis conducted by Edward Denison estimated that R&D accounts for 20 percent of U.S. economic growth between 1939 and 1957.
- Return on investment analysis conducted by Zvi Griliches and Edwin Mansfield showed rates of return for R&D investments to be as high as 40 percent. In similar work, Mansfield used growth accounting analysis to estimate the social rate of return to R&D investment: he estimated that the social rate of return to R&D investment was 28 percent for the years 1975-1985.

Despite these efforts, demonstrating direct causality between S&T investment and economic growth remains difficult. One reason is because a great deal of scientific research has little or no economic potential for commercial projects and services for domestic consumption or foreign export. Examples are basic research in physics and astronomy. Even science that has commercial application requires a country to have a certain level of sophistication in its physical infrastructure and legal, financial, educational, industrial, and commercial institutions to turn that knowledge into products and services for the marketplace (Salamon et al., 1994).

Many studies have suggested a strong link between S&T investment and economic growth and productivity enhancement in advanced industrialized countries. For the developing countries, evidence of this link is more limited and less conclusive. Specific cases where S&T investment appeared to have made a positive impact on economic growth start with Japan and then more recently in South Korea, India, and Brazil. Econometric work done by Zvi Griliches and Robert Evenson during the 1970s for the World Bank and the Consultative Group on International Agriculture Research (CGIAR) showed a high economic rate of return for both basic and applied scientific research related to agriculture.

Neither is it clear whether developing countries would benefit from a higher social rate of return in public investment in S&T than private investments. The experience of advanced industrialized countries show a high social rate of return for government spending on S&T in these economies. The cost of scientific research and technology development is high. Since it is difficult for private firms to capture all of the benefits of these investments, total R&D spending, if left only to private sources, will result in under-investment and a country would lose many potential social benefits. This observation has been a basis for public investment in the creation of knowledge- sometimes called "basic research" or "pre-competitive" research – which is generally considered to be a "public good" (Smith et al., 1996).

While one could extrapolate from this research to say that developing countries should make similar public investments in S&T, it is not clear whether the conditions that exist in developing countries are sufficient to produce outcomes similar to those in the developed countries. In fact, it is reasonable to assume that the rate of return to a given investment in S&T is determined in large part by the overall level of S&T capacity that is already extant in the country. In other words, the high social rates of return observed in developed countries reflect the presence of highly connected technical and economic systems that are able to diffuse and apply the results of new research. Since similar systems are more limited or entirely absent in developing countries, the return on a given investment in S&T research and development would be much lower. Indeed, at least one economic study of a developing country has found that technological change can only account for between 7 and 9 percent of its economic growth over the past 20 years (Yuhn et al., 2000).

Nonetheless, many policymakers in developed and developing countries assume that benefits will accrue from investment in S&T. They see S&T as an engine for development despite the lack of a theoretical or quantitative link between S&T research and economic development. As Skolnikoff has said, "perhaps too often, technology has been elevated to near-mythic status, as the 'magic bullet,' that will guarantee development." A successful S&T endeavor is a gradual process that involves training, education, infrastructure, continued investment, competence and experience. Thus, S&T transferred from developed countries to developing countries, through investment, development assistance, or other means, will not lead to economic growth if developing countries do not have the capacity to absorb and use that S&T (Skolnikoff, 1993).

Although the link between S&T and economic growth in developing countries is unclear, increasing international acceptance of a broader, more comprehensive approach to, and view of, development affirms the importance of S&T capacity to

development. This study did not directly address these areas, but many development experts and policymakers agree that building S&T capacity helps developing countries to create the social capital necessary for development, and particularly in a globalizing world. In 1998, Joseph Stiglitz proposed that the creation of formal and informal institutions and interaction, or social capital, as central to development. He stressed cooperation among all stakeholders to decide on development goals and appropriate ways to attain them.⁸

Development, in this new paradigm, is more holistic. Economic development is just one expression of development, and policymakers assert that it must be socially and environmentally sustainable. Many development experts and policymakers suggest that developing countries need "ownership" of their development strategy and implementation.⁹ This means bringing knowledge and skills into dialogue with development partners (e.g., donor governments, international development agencies and multinational corporations) and stakeholders. They must be able to participate in international forums, which define scientific standards for international trade, public health, education, telecommunications, etc. Thus, in the best of scenarios, building S&T capacity in developing countries may help them define and choose development options, acquire indigenous capacity to create human capital and appropriate institutions and infrastructure for development, and to have a more equitable voice in international affairs.

Furthermore, globalization intensifies the artificiality of national boundaries. The speed and volume of international movements of people and commodities in the world today is unprecedented. We are increasingly aware that occurrences in a single country have larger international, even global, implications. The environment, for example, provides shared benefits. Consequently, all nations have an interest in curbing loss of biodiversity in Indonesia, the spread of HIV in Africa, and persistent organic pollutants in Canadian lakes and rivers. Building S&T capacity in developing countries will better enable them to play substantive roles in international activities to monitor and mitigate these shared concerns.

⁸ Stiglitz introduced his proposals in his Prebisch Lecture at the UN Conference on Trade and Development in 1998.

⁹ The World Bank and the International Monetary Fund now require borrower countries to submit poverty reduction strategy papers as the basis for concessional lending and for debt relief within the Highly Indebted Poor Country Initiative.

Methodology Used for this Study

The focus of this study is whether merit-based collaboration between researchers in developed and developing countries builds scientific capacity in the latter, particularly in how funds from the wealthiest science and technology performing countries are supporting collaboration in or with the developing world. This study presents data examined, collected, and analyzed from five different perspectives and sets of sources:

- A composite S&T capacity index of 150 countries created from available indicators of S&T investment, infrastructure, and output. This index gives an idea of where scientific strengths exist and where opportunities may be exploited for the purposes of analysis as well as for targeting efforts to encourage future collaboration;
- A set of interviews with US-based scientists who have or are working collaboratively with counterparts in other countries to identify whether collaboration is creating capacity;
- A review of U.S. government spending on international S&T collaboration as a way to gain insight into how a developed country spends money on these types of projects. (The United States spends about 50 percent of global funds dedicated to R&D);
- A review of existing policy analyses and bibliometric literature for patterns of cooperative linkages; and
- A review of literature related to S&T and development.

These varying sources were consulted because no one source reports on the extent of international S&T collaboration between developed and developing countries. The only set of data that comes close is RAND's RaDiUS database,¹⁰ which gives details about projects funded by the U.S. government, and which allows analysts to find those projects that involve international partners. To fill out this picture further, we examined indicators of spending and publication, and asked scientists about their collaborative activities and experiences. Together, these data sets and information sources provide a better picture than can be gathered by using any one source. Even then, the picture is hazy and would benefit from sharpening through further study and analysis.

¹⁰ RaDiUS is the first comprehensive database of U.S. federal government R&D spending. It contains data for projects, programs, and bureaus of the federal R&D agencies, detailing spending of more than \$70 billion each year by the U.S. government.

Data on graduate training, post-doctoral fellowships, and visiting professorships by developing country researchers in developed countries, or vice versa, also provide useful information on international linkages. These activities clearly have an important role in supporting international S&T collaboration, as indicated by many responses in the interviews conducted for this study. RAND did not develop new data related to movements of people but existing data is described briefly in Section 3. Additional research on movements of people, particularly the question of "brain drain" would be useful.

It is no easy task to measure the capacity in a developing country to conduct world-class scientific research and technological development within its educational system, public institution, and the private sector. Since science is a bottom-up process driven by individual intellectual curiosity, much of this capacity exists at the individual level. Yet, the individual scientist operates in larger institutional and societal settings. Thus, the presence of certain activities at the institutional and societal level is critical to support scientific capacity building at the individual and national level. These capacity building activities include:

- Purchase of scientific or technical equipment;
- Training of university students and faculty;
- Creation of new university departments or centers for research;
- Establishment of new laboratories;
- Creation of new data sets;
- Creation of new information exchange forums and mechanisms, e.g., Web sites and electronic bulletin boards;
- Publishing of international scientific or technical papers;
- Establishment of new academic, peer-reviewed journals;
- Development of a new research protocol; and
- Strengthening the connection of local scientists to the international scientific community.

Organization of this Report

Following this introduction, Section 2 describes the S&T Capacity Index developed by RAND for this study. Section 3 presents findings from our analysis of the RaDiUS search and patterns of co-publication, as well as the work of others

addressing similar questions, in order to illustrate the growing scientific links between the developed and developing countries. Section 4 describes the results of a series of conversations with scientists in the United States who are working with researchers in developing countries. Section 5 presents observations and recommendations for increasing the effectiveness of S&T collaboration for capacity building in the future. Appendix A provides a numerical table containing the data inputs to the S&T capacity index. Appendix B lists the questions and summarizes the answers of U.S. scientists in our discussions with them. A bibliography provides ideas for further reading in this area.

S&T Capacity Across Countries

Countries have different capacities to conduct scientific research and technological development. Many factors contribute to scientific capacity: national infrastructure (e.g., communication and transportation systems, legal and regulatory structures); the pool of scientists, engineers, and other trained workforce; laboratories and other research facilities; and academic institutions. Capacity building is a continuous process even in the most scientifically-advanced countries, although the term generally refers to efforts to enhance science in developing countries where a shorter (or no) history of investing in S&T limits their ability to solve domestic problems or participate in international-level R&D.

The productivity and return on S&T investments in developing countries is most likely lower than the same funds spent in developed countries. Increases in R&D funding, for example, will not increase capacity if few educated scientists are available to put those resources to work. Few measures exist, however, that show the productivity of R&D dollars spent by any one country or institution. It can be observed, however, that scientific spending in advanced countries results in more papers overall and in greater economic externalities than funds spent in developing countries. Even so, it is very difficult to show the relationship between S&T capacity, productivity, and output.¹¹

While collaboration among developed and developing countries has been referred to as "North-South" linkages or "donor-host" relationships, regional groupings or unequal partnerships no longer adequately represent global relationships in S&T. In order to facilitate discussion of international capacity building and make it possible to identify when collaboration may offer potential capacity-building benefits to developing countries, we developed an index of scientific and technological capacity for 150 nations. The intent is to make it possible to go beyond highly general and generic discussion of scientific capacity, while at the same time not becoming lost in an unmanageable level of detail regarding efforts in individual countries.

¹¹ An interesting treatment of this can be found in Charles Weiss's chapter in Evenson's book (1990) detailing stages of S&T as they relate to modernization and economic development.

Developing an Index of S&T Capacity

This index is constructed from available national-level data from a number of sources.¹² The components selected to make up the index are as follows:

- The per capita gross national product (GNP) of the country to serve as a proxy for general infrastructure;
- The number of scientists and engineers per million people to capture the human resources available for S&T activities;
- The number of S&T journal articles and patents produced by citizens of the nation to characterize S&T outputs;
- The percentage of GNP spent on R&D to measure the society's level of input into S&T;
- The number of universities and research institutions in the nation per million people to characterize the infrastructure for S&T;
- A measure of the number of the nation's students studying in the United States adjusted for those who chose not to return home at the conclusion of their studies to characterize the country's contact with external knowledge sources;¹³ and
- The number of patents filed through the U.S. Patent and Trademark Office (USPTO) and the European Patent Office (EPO).

In order to combine these disparate components into a common index, the value of each national characteristic is compared to the international average. National "performance" in each characteristic is ranked based on the number of standard deviations of the national value away from the international mean. If the value of the characteristic is above the mean, this would produce a positive contribution to the capacity index; if it is below the mean, it is a negative contribution. The size of the contribution is determined by the country's distance from the international average. These performance values are weighted based on judgments about the relative importance of each factor for creating science and technology capacity, with the most heavily weighted factors being those inputs

¹² In each case, metrics are selected to be the most appropriate proxy available for the underlying characteristics they were intended to represent. As a result, in some cases per capita measures are used and sometimes a value is used independent of population depending on the characteristic of interest.

¹³ The total number of students studying in the U.S. is adjusted downward by a fraction of the individuals who chose to remain in the U.S.

that have a direct relationship to the ability of the nation to conduct scientific or technical inquiry; the weighted values are then summed to generate the aggregate S&T capacity index. The weighting scheme follows:

- 1) A greater weight (3 points) is assigned to indicators of actual capacity to conduct S&T: (a) the percent of GNP invested in R&D and (b) the number of scientists and engineers per million population.
- 2) A lesser weight (2 points) is assigned to the figure representing the primary output of the S&T system: the number of science and technology journal articles.
- 3) The least weight (1 point) is assigned to indirect factors such as (a) the GNP per capita, (b) the number of university and research institutions in a country, (c) the number of students studying in the U.S., and (d) patents filed in the US and Europe.

Explanation of Figures in the Following Section

The numerical value of the capacity index was used to order countries and group them into four classes of S&T capacity. (Appendix A has a supporting data table, including the calculated S&T index values for each country.) The following sections provide a description of the four groupings of countries by S&T capacity that emerges from this index. In each section, the combined S&T indices for the nations in that class are represented graphically on the charts. The bar indicating the S&T capacity for each country is further broken down into different colors depicting the contribution of each index component to the overall value. The length of each segment reflects how far above or below average the country falls. The meaning of each color is as follows:

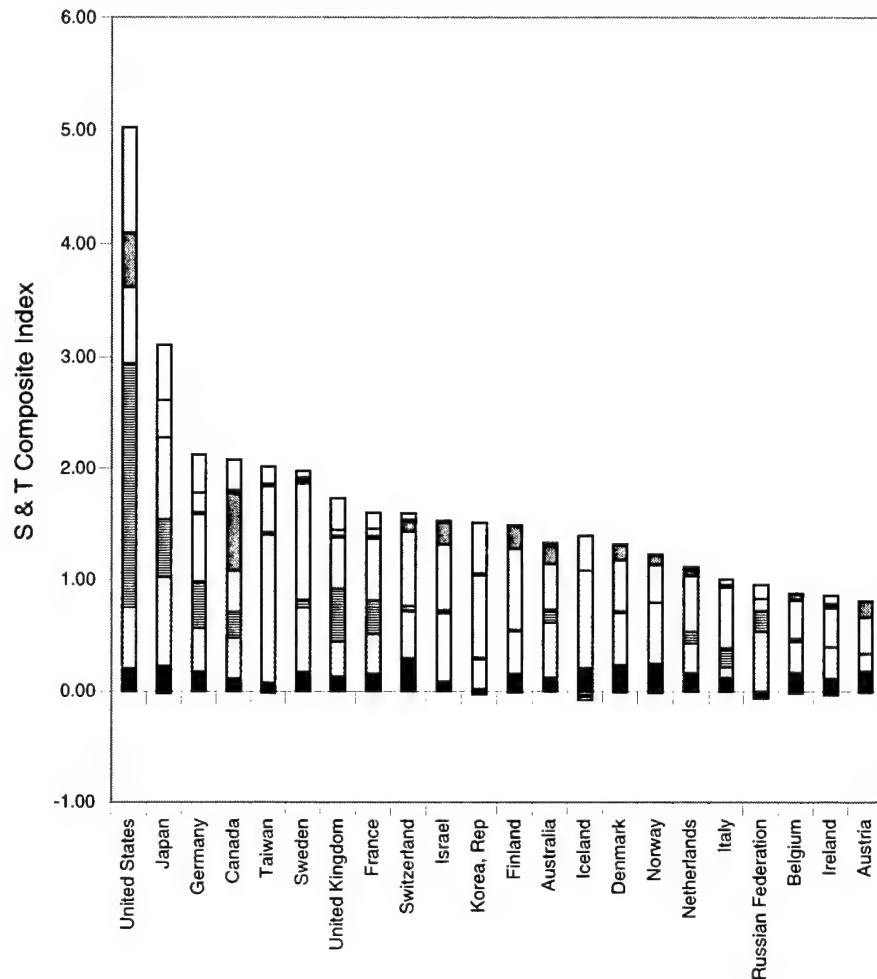
■ GNP per Capita	□ Scientists and Engineers	■ S&T Journal Articles
□ Expenditure for R&D	■ Research Inst. and Univ.	□ USPTO/EPO Patents
□ Students Studying in US		

Scientifically Advanced Countries

The 22 nations having the most positive ranking in scientific capacity are termed scientifically advanced countries (SAC). These nations show a positive value on the index, meaning they all have greater S&T capacity than the international mean. These countries generally have capacity in all major areas of S&T. These countries are responsible for 86 percent of all scientific articles published in

internationally recognized journals, and they fund between 85 and 90 percent of all the world's R&D (NSB, 2000).

Figure 2.1: Scientifically Advanced Countries on an S&T Composite Index

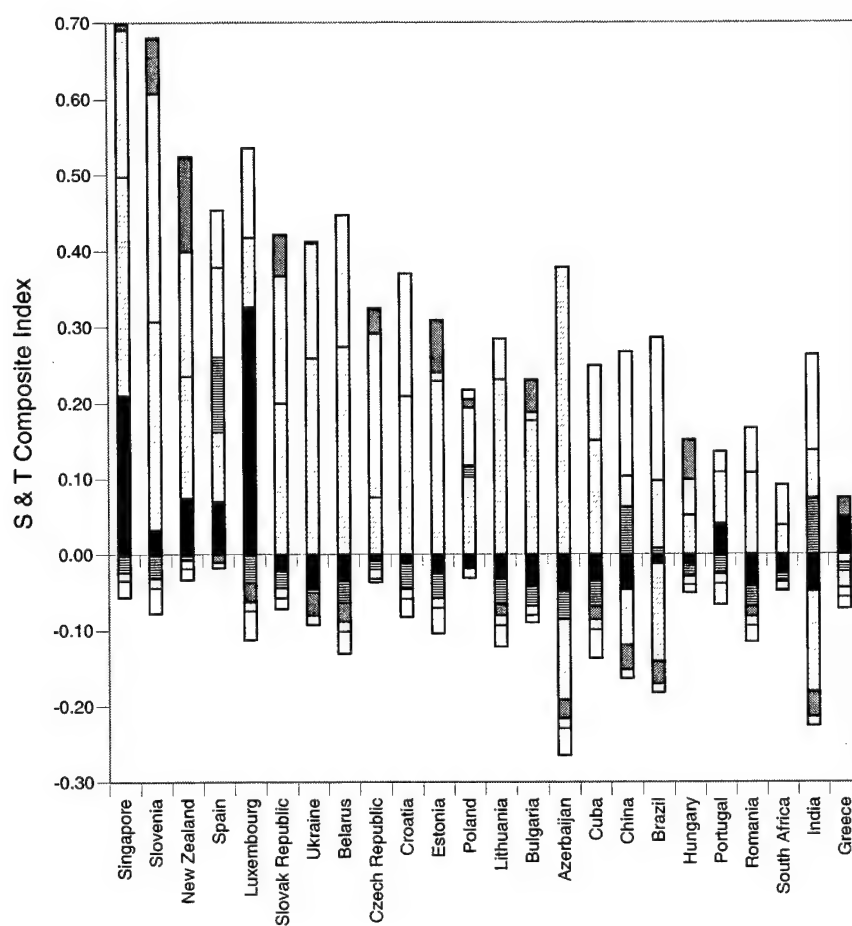


Scientifically Proficient Countries

The next group of 24 nations is termed scientifically proficient countries (SPCs). They possess an overall S&T capacity index value at or over the international average, but they are not as uniformly capable as the advanced nations. Values for some capacity components may exceed the international average while others may fall below the mean. Some of these countries display world-class strength in

particular areas or subfields of science. These countries have made investments in the infrastructure and R&D required to build a science base, and these investments are showing results. A number of these countries, notably Spain, Brazil and Poland, have experienced significant gains over time in their roles in international S&T.

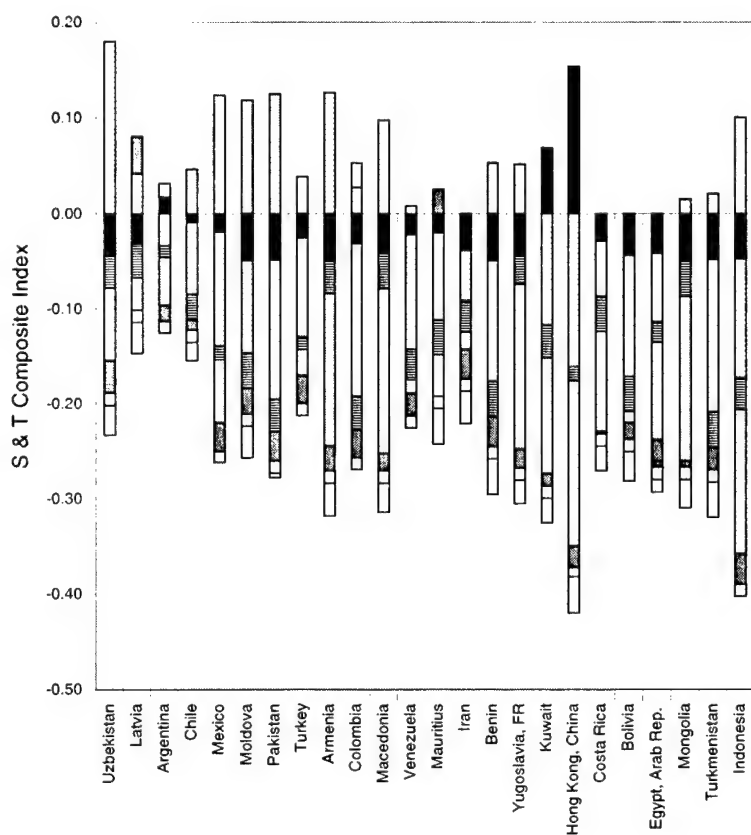
Figure 2.2: Scientifically Proficient Countries on an S&T Composite Index



Scientifically Developing Countries

The next 24 countries are termed scientifically developing countries (SDCs). Although these nations have made some positive investments—reflected in the fact that some components of the index exceed the international mean—their overall scientific capacity is below the world average. The investments that have been made, however, do allow these countries to participate in international S&T. These countries are seeking to invest further in science and, in some cases, they have good capabilities which attract international partners. Several of these countries are poised to move into the "proficient" category, but factors such as overall GNP or other infrastructural factors are keeping these countries from being considered among the scientifically proficient countries. This is the case, for example, for Latvia, Argentina, and Chile.

Figure 2.3: Scientifically Developing Countries on an S&T Composite Index



Scientifically Lagging Countries

The remaining 80 countries assessed in this index fall into the category of scientific lagging countries. These countries fall below, and in most cases well below, the international mean for all the components of the S&T capacity index. In many cases, these countries have little or no capacity to conduct international-level science. In a number of cases, scientific capacity that does exist has resulted from a natural or geographical resource located in these countries. In other cases, problems with infectious disease, natural disasters, or pollution, mean that international partners are interested in helping these countries, but they often find little indigenous capacity to tap for collaborative projects. This may offer opportunities for capacity development over time.

Figure 2.4: Scientifically Lagging Countries (1) on an S&T Composite Index

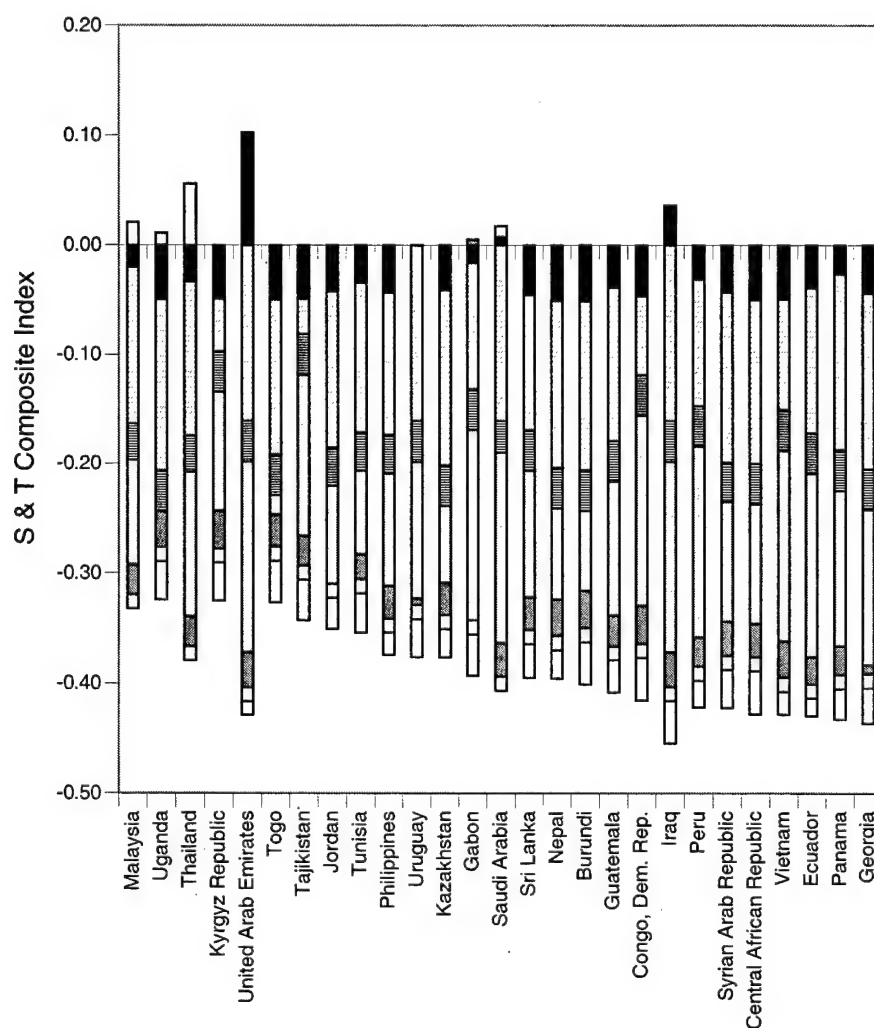


Figure 2.5: Scientifically Lagging Countries (2) on an S&T Composite Index

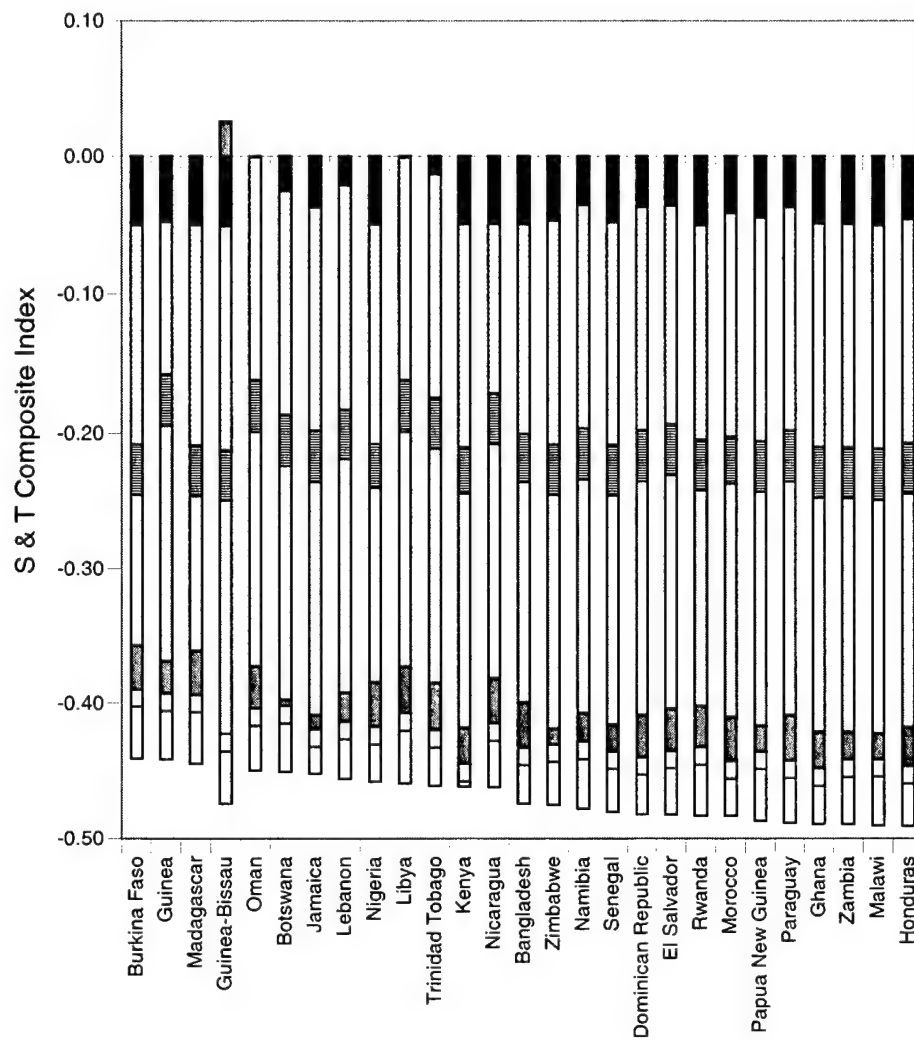
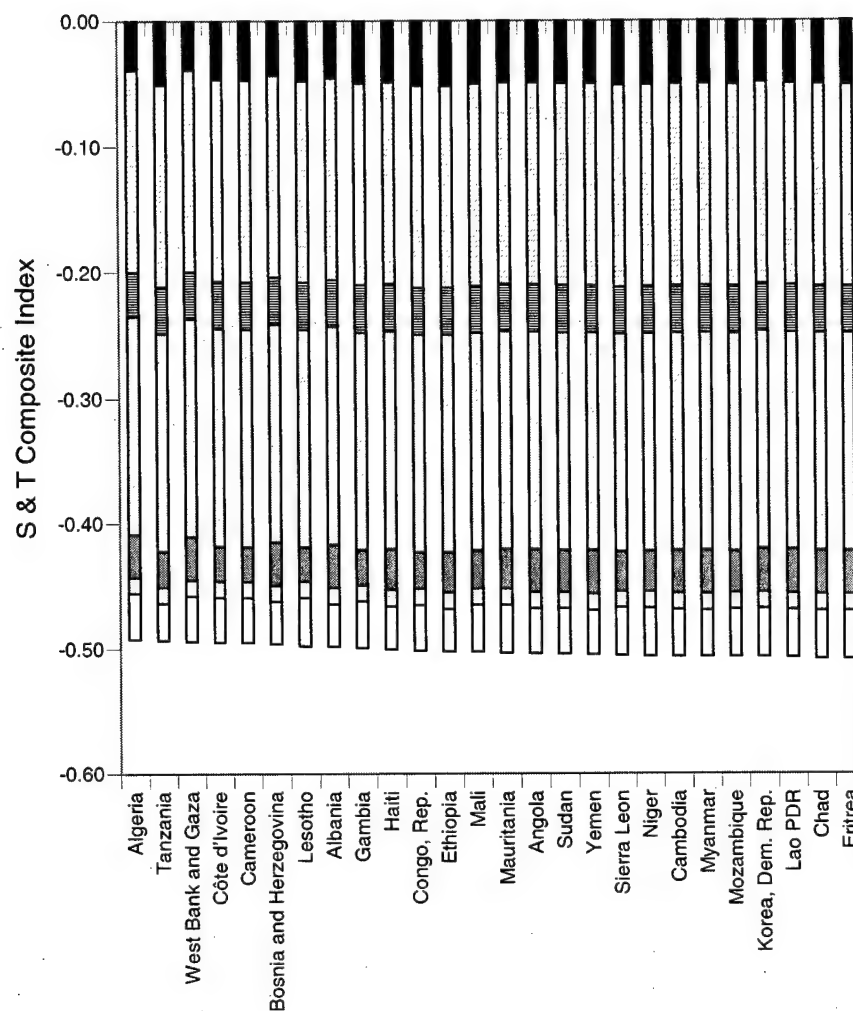


Figure 2.6: Scientifically Lagging Countries (3) on an S&T Composite Index



Limitations of this Approach

This index provides a useful parsing, but the data should not be over interpreted. Small differences in the calculated index are likely to reflect as much the shortcomings in the data as subtle differences in research and technical capabilities. This index is also a static representation. It does not reflect the fact that the list of SACs and SPCs include several countries with centuries of scientific tradition and significant investment that outstrip that of scientific newcomers listed next to them. Nor does it capture the dynamism of some countries that are rapidly moving up the scale relative to others. The index also

does not capture the complementarity and synergy between different types of capacity investments. S&T professionals need places to work and funds to support their research. As a result, although a large investment in only one of these areas would increase the S&T index value, it might not effectively increase overall capacity. Moreover, the index is based upon political boundaries: many students of science note that world science is not so easily parsed into boundaries and borders. One example is India, although falling 23rd in the list of SPCs, is among the top performers in mathematics. Other examples are China, which does world-class seismology research, the Philippines, which is an international leader in rice research, and Chile, which has developed strength in astronomy. In these cases, expertise grows out of deliberate government policies to support S&T capacity building, actions by international development organizations, the unique geography, ecology, history, or social conditions in a country, or the presence of special research equipment and laboratories. This overall index does not represent centers of excellence in different countries: such a mapping would show a different representation of specializations, linkages and strengths.

In spite of these caveats, this index provides a way to place nations on a spectrum of scientific capacity for the purposes of discussion and analysis. To the extent that this effort highlights the limitations of available data sets, it also serves to emphasize the need for more extensive and accurate reporting of the relevant information.

Collaboration between Advanced and Developing Countries

Recent inquiries into the nature of development assistance have found that international collaboration is replacing other models as the preferred method of building scientific capacity (Gaillard, 1994; Salomon, 1994). The shift towards a collaborative model has resulted from the convergence of several factors, including:

- S&T investments being made in many more nations now than was the case 15 years ago, enabling broader collaborative scientific linkages;
- The global or transboundary nature of some scientific problems requiring scientists to travel around the world to seek data and conduct experiments; and
- Less expensive travel and abundant information technology facilitating exchange.

Moreover, a number of wealthier countries that once devoted resources to "research-for-aid" are reluctant to continue providing aid without reciprocity or clear benefit. They are searching for a new model and international S&T collaboration offers an attractive alternative.

Estimating Spending

Funding for collaboration happens in two ways: 1) through public R&D spending and 2) through funding traditionally set aside to provide "research-for-aid" specifically aimed at development. Spending by scientifically advanced countries on international S&T collaboration overall ranges from 5 percent for the U.S.,¹⁴ which is the lowest among advanced industrial economies, to perhaps as much as 25 percent in the case of smaller, advanced economies. These funds include both the scientific R&D monies and the research-for-aid funding. Science

¹⁴ See Caroline Wagner, "International Cooperation in Research and Development: An Inventory of U.S. Government Spending and Framework for Measuring Benefits," RAND, 1997 and Caroline Wagner et al., "International Cooperation in Research and Development: An Update to an Inventory of U.S. Government Spending," RAND, 2000.

R&D funds are generally allocated in a "bottom-up," peer-reviewed process, with funds granted to excellent proposals regardless of whether they involve international collaboration. Spending dedicated to research-for-aid programs tend to be "top-down" in their mission focus and allocation.

Estimates of spending on international R&D collaboration and research-for-aid are difficult to make. Table 3.1 provides estimates that give a sense of the scope of these activities, but these numbers should not be seen as definitive. In fact, much work needs to be done in order to get a clearer picture of spending on both these endeavors. In reviewing the literature, we find that total spending on research-for-aid by advanced countries is estimated to be between \$1 and \$2 billion per year. (Lewis, 1987; Gaillard, 1994). A subset of these estimates, broken down by country, is included on the table. These figures are based largely on 1984 survey data that has not been formally published, but which is available from the Canadian-based IDRC. They are a subset of all official development assistance (ODA), which, for the OECD countries, totaled \$49 billion in 1997 (OECD, 1999-1).

Funds dedicated by the advanced countries to collaborative research with developing countries appear to be about \$1.4 billion per year. Japan is the largest spender in this category, with an estimated \$406 million being spent on collaborative R&D based on estimates made by Japanese academic sources. Research-for-aid is likely a larger figure; estimates of Japan's research-for-aid range between \$82 million and \$5 billion. The United States is the next largest spender in this category, with nearly \$400 million in funds going to collaborative R&D with developing countries and about \$240 million devoted to research-for-aid activities. The majority of this spending goes to collaborative research with proficient (China, India, and Brazil are the leading partners) and developing (Mexico, Costa Rica, and Venezuela are the leading partners) countries. Very little is spent on research with lagging countries. Of these, the majority is spent with Africa. Most projects mentioning a scientifically lagging country are conducting research about, not with, that country. Most of the research-for-aid money, however, goes to fund work in or with a developing country.

Since its inception, the EU has developed several programs to encourage S&T cooperation with developing countries. Under the Fifth Framework Program for Research and Development (1992-1996), \$50 million was allocated annually to S&T cooperation with developing countries. Between 1982 and 1994, an additional \$6-\$8 million was allocated annually for this purpose under the International Scientific Cooperation Scheme (ISC) outside of the Framework (European Commission, 1997). The Framework included the Science and Technology Development (STD) program, which ran from 1991 to 1994 and

included all developing countries. Agricultural studies and activities had the largest share of support at \$70 million. This was followed by health-related projects at \$40 million.

The ISC scheme (1991 to 1994), a program aimed at creating centers of excellence through joint research projects and research fellowships, operated outside the Framework; the EC reports that this program had about \$100 million in total funding. A total of 509 joint research contracts were signed between institutions in the EU and developing countries, and 646 fellowships were awarded. The ISC funded scientists in more than 25 nations and eight scientific subject areas. The more scientifically sophisticated developing countries, including Argentina, Mexico and Israel, were most active in joint research projects, while China and India far surpass other countries in the number of fellowships they were awarded (European Commission, 1997).

Total EU spending on international S&T cooperation with developing countries totaled about \$100 million per year between from 1987 to 1998.¹⁵ Spending by individual member countries would be counted on top of this; although most of these contributions can be assumed to be small, a few countries stand out in their support. For example, Denmark allocated almost \$10 million bilaterally *via*

Table 3.1: Estimates of Single Year Spending for Collaboration, Research-for-Aid, and Total Official Development Assistance by Key Countries

Country or Region	Spending on Collaborative R&D with SPCs and SDCs, 1997 or latest available (Millions of US\$)	Spending on Official Direct Assistance and the Subset of that Spending considered "Research-for-Aid," 1997 or latest available (Millions of US\$)	
		Research for Aid for Development	Total Official Development Assistance
Belgium			764
Canada	59 ⁴	82 ^{6,7}	2,045
Denmark	10 ¹		1,637
EC	122 ²		5,261

¹⁵ This Framework provides separate allocation for international S&T cooperation with Central and Eastern European countries and the Newly Independent States of the former Soviet Union. The sum for the 1994-98 period was ECU 247 million, equal to the amount for S&T cooperation with developing countries. Another ECU 49 million was for activities to coordinate European scientific and technological cooperation and ECU 32 million was for cooperation with non-European industrialized countries.

France	328 ¹	204 ^c	6,307
Germany	3 ²	118 ^c	5,857
Ireland			187
Italy	2 ²		1,266
Japan	406 ⁵	86 ^{b,8}	9,358
Netherlands	3 ²	81 ^a	2,947
Portugal			250
Spain			1,234
Sweden	57 ¹	20 ^a	1,731
UK	64 ¹	38 ^c	3,433
USA	393 ³	236 ^c	6,878
Estimated Total:	1,447	865	49,155
	<p>1. Institute for Development Studies, 2000 (Converted to US\$)</p> <p>2. European Commission, 1997 (Converted to US\$)</p> <p>3. RaDiUS Database</p> <p>4. Personal communication from Ministry source. (Estimate based on 3% of government funded R&D)</p> <p>5. Personal communication from Japanese academic source.</p> <p>1. Institute for Development Studies, 2000 (Converted to US\$) includes funds of the IFS based in Sweden (1999)</p> <p>6. Values from Lewis, 1987 (most are 1984 estimates)</p> <p>7. In 1988, Canada was estimated to provide the much larger value of \$2 billion in tied aid and capital assistance (Weiss, 1989)</p> <p>8. According to the Japanese government WWW site, they provide the much larger value of \$5 billion in "total grants and technical assistance" (1998)</p> <p>9. USAID & USDA Int'l R&D Budget (FY1997) – Lewis, 1987 Estimate was \$256 million (for 1984)</p> <p>All ODA values from OECD statistical and electronic publications</p>		

Danish research, four research institutions in Denmark, and the ENRICO program which offered twinning projects between Danish and developing nation institutions. The remainder of the approximately \$53 million Denmark allocated to development research (approximately 3 percent of ODA) was distributed through multilateral channels (Institute for Development Studies, 2000). Sweden also supports a significant amount of development research through its International Development Cooperation Agency. In 1999, approximately \$57 million was allocated to research cooperation. About one-third of this funding is allocated to bilateral research cooperation, one-third to regional research programs, one-quarter to international multilateral programs, and the remainder to special projects and initiatives (Institute for Development Studies, 2000).

Examining Co-authorship Patterns

Although spending data for international S&T collaboration is sparse, it is possible to look at indicators of co-authorship to broadly characterize the extent of existing collaboration. In order to identify patterns of collaboration among developed and developing countries, we examined co-authorship of articles published in internationally recognized scientific journals. Worldwide, there has been a 17 percent increase in the number of scientific and technical articles published between 1986 and 1997. When examined according to the groupings of countries used for this study, the patterns provide insight into the growing strengths of developing countries as well as the willingness of advanced country scientists to seek out and work with them.

Co-authorship data does not provide insight into the amount of funding dedicated to these activities. It would be difficult even to attribute an average amount of funding to each collaboration. Science in the United States costs about \$250,000 per researcher per year. In contrast, the amount needed to support a researcher of the same caliber working in Peru or Kenya, for example, would be considerably less. Nevertheless, since research institutions are listed on publications, it can be assumed that these linkages represent spending on the part of both countries involved in a collaboration.

There is an increasing amount of scientific cooperation reflected in co-authorship, and an even greater rate of increase in the amount of international cooperation. When examined geographically, S&T strength has extended to new areas of the world (Narin, 1991). Scientifically developing countries, and in some limited number of cases scientifically lagging countries, are increasingly represented as participating in internationally-recognized research.

Analysis of publications data—called “bibliometrics”—shows that cooperative relationships develop over a long period of time and, once established, do not change quickly (Okubo et al., 1992). With this in mind, we have examined bibliometric literature for the last 15 years in order to identify patterns and trends of cooperative linkages between advanced and developing countries.

Previous studies on the extent of collaboration between advanced and developing countries have shown:

- Scientifically advanced countries are collaborating and co-publishing with scientifically proficient and developing countries at an increasing rate;
- Scientifically advanced countries have little interaction with scientifically lagging countries;
- Scientifically advanced countries are most likely to collaborate with each other;
- Although scientifically developing and proficient countries mainly collaborate with scientifically advanced countries, collaborations between SDCs & SPCs are increasing;
- All countries are likely to collaborate for reasons that go beyond scientific compatibility; and
- Collaboration occurs at a high rate in certain fields and in scientifically proficient and developing countries that are known to do world-class research.

Other observations of note include the fact that countries which only recently would be considered scientifically advanced (such as South Korea and Israel) still have collaboration patterns similar to those of developing and proficient countries; that is, they still mainly collaborate with SACs rather than with developing countries. Moreover, while SACs have a robust set of interactions among themselves, SDCs do not. SDCs are much more likely to collaborate with an advanced country than with another developing or lagging country, even when they may be geographically close to or have similar problems to these countries. Developing countries are more likely to be publishing in fields reflecting national needs such as agriculture and medicine; SPCs are more likely to publish in the physical sciences such as chemistry and physics which support industrialization. SACs are more likely to publish across the whole spectrum of sciences and, increasingly, in the biological and earth sciences.

When examined regionally, countries with the most active collaborations are found in the Commonwealth of Independent States and the Balkan countries. The countries with the least amount of international collaborations are those in Latin America. The region most dependent on SACs for collaboration is Africa and the Middle East. Due to the sheer size of its scientific output, the United States is a principal collaborator for most countries and is quite important in present-day science. Its size basically determines the average rate of international collaboration by scientific field. A 20 percent decrease in the proportion of co-authored papers is detected when U.S. figures are removed from the world average (Luukkonen et al., 1992). Figures 3.2 through 3.8 show the substantial amount of collaborations between the SACs and the rest of the world.

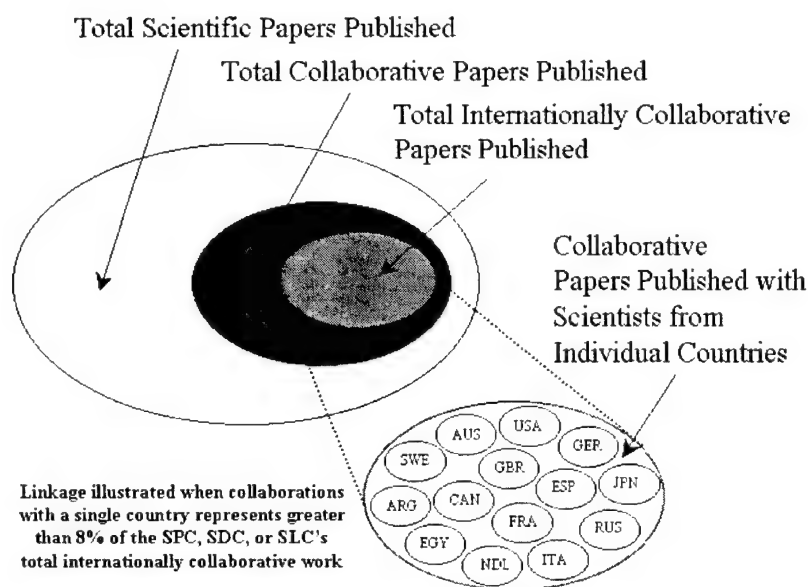
Explanation of Diagrams in the Following Sections

In order to identify countries involved in collaboration, we have developed diagrams to depict the linkages for internationally co-authored papers in scientific and technical research during the period from 1995 to 1997. Seven of the eight diagrams in this section focus on the linkages that scientifically advanced countries have formed with the scientifically lagging, developing, and proficient countries. The eighth diagram focuses on the cooperative linkages among scientifically proficient, developing, and lagging countries.

To highlight the linkages that SACs have formed with the SPCs, SDCs, and SLCs, the scientifically advanced countries¹⁶ are represented by circles based on size relative to their gross domestic expenditure on research and development (GERD), in million current PPP\$ (purchasing power parity) (OECD, 2000). The links connecting countries represent the percentage of papers co-authored between two particular countries (links are only illustrated when the percentage of the SPC, SDC or SLC's internationally co-authored papers with a single partner country exceeds 8 percent of its total—see Figure 3.1). Each scientifically lagging, developing and proficient country is placed in close proximity to the SAC with which it has the highest percentage of co-authorship. The data mainly comes from the National Science Board's (NSB) *Science & Engineering Indicators – 2000*. Two sets of diagrams have been developed, the first by region and the second by scientific capacity.

¹⁶ In this case, we are using Australia, Austria, Canada, Finland, France, Germany, Israel, Italy, Japan, Korea, The Netherlands, Russia, Sweden, Switzerland, Taiwan, the United Kingdom, and the United States.

Figure 3.1: Graphical Explanation of the Country-Country Linkages Pictured in the Subsequent Figures



Regional Patterns of Collaborative Links

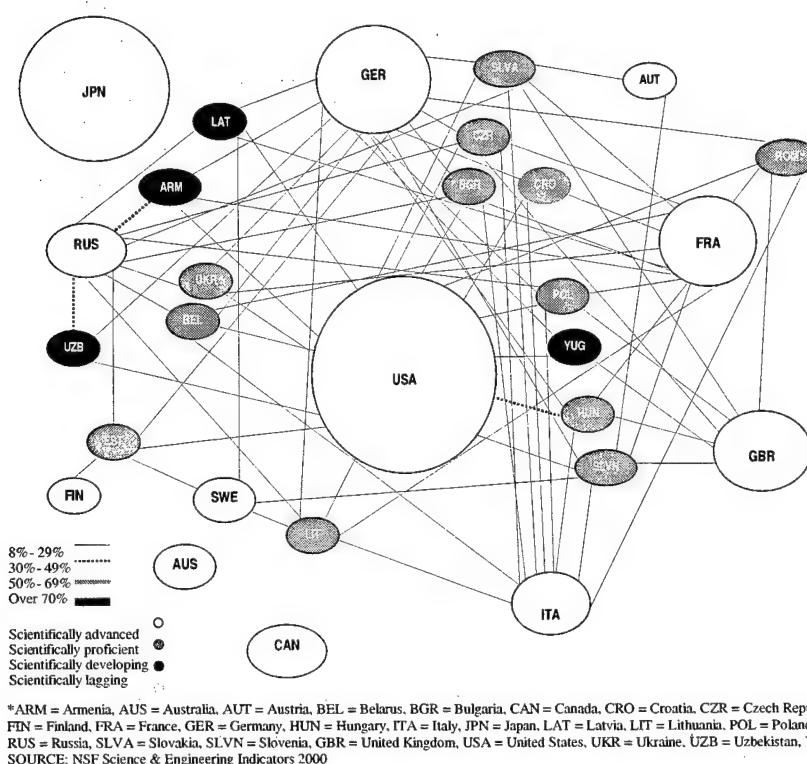
Commonwealth of Independent States (CIS) and Balkan Region

As shown in Figure 3.2, there are numerous collaborations occurring among the advanced countries and the CIS and Balkan countries. Germany and the United States both have collaborations with all 16 countries in this region. France follows behind with 13 collaborations, Russia with 11, and Italy with ten. Each country has an average of five different advanced countries with which it has co-authorships. This average is higher than in other regions. There was no co-authorship data available for any of the scientific lagging countries within this region. Armenia and Uzbekistan both have one-third to one-half of their collaborations with Russia, as does Hungary with the United States. Close proximity may explain why Germany, France, United Kingdom, Italy, Sweden, Russia, Finland, and Austria are collaborating with this region, yet distant countries such as Canada, Japan, and Australia are not.

Bibliometric data shows that Eastern European countries have high levels of collaboration in chemistry and physics. Poland and Romania have the highest levels of activity in chemistry and non-ferrous metallurgy in this region. Eastern

European countries are most interested in the steel, food, and textile industries with research mainly in these fields as observed by publication patterns. One example is Hungary, which has well-established iron and steel industries. Yet, Hungary is also involved in pharmaceuticals, and publishes research in international biochemical and clinical journals (Dore et al., 1996).

Figure 3.2: Patterns of Co-authorship in the CIS and Balkan Region



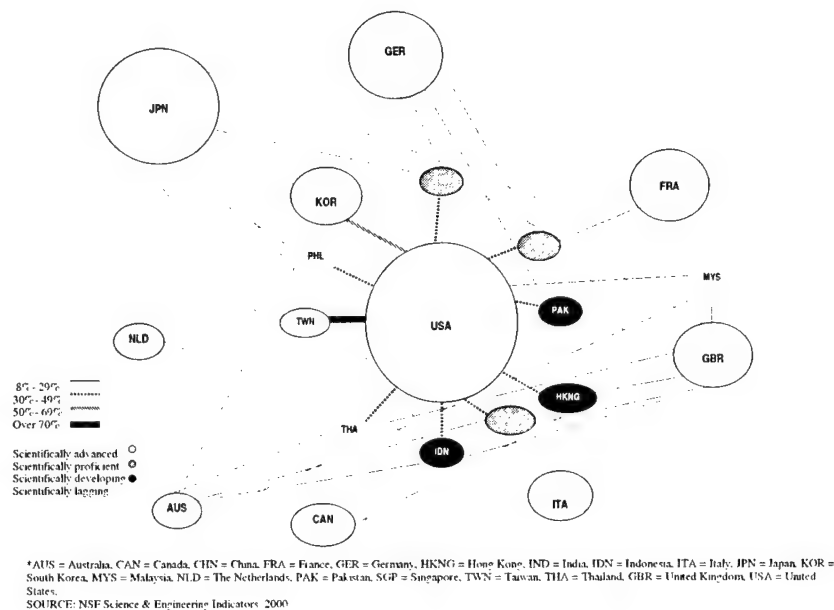
Asia

As shown in Figure 3.3, advanced countries have strong ties with the Asian countries; among the SACs, the U.S. predominates in this region. The U.S. has between 40 to 49 percent co-authorship linkages with China, India, Pakistan, Hong Kong, Singapore, Indonesia, Thailand, and the Philippines. Many of the Asian countries are former colonies of the United Kingdom, which may explain why Britain has several collaborative efforts within this region. Japan and Australia also have a number of collaborations in this region, in part due to

geographic proximity. Figure 3.3 focuses primarily on the relationships between SACs and lagging, developing, and proficient countries. Two exceptions are South Korea and Taiwan, both new scientifically advanced countries, which have the majority of their collaborations with other advanced countries rather than with the SPCs, SDCs, and SLCs.

Asian countries have varied bibliometric patterns. The countries in this region focus on engineering, chemistry, physics, and materials sciences (especially South Korea). China and India have features in common: both are underdeveloped but are on the path towards industrialization. Patterns show that China's focus is on physics and engineering, while India's is on chemistry (Okubo et al., 1992). Of publications reported in international journals, 17 percent of all Chinese publications were co-authored in 1985 (Schubert et al., 1990), but that increased to 27 percent by 1994 as China continued to gain visibility and open up its science community (Mely et al., 1998). Science and engineering for agriculture is the basis of much of Asia's research efforts. Due to the heavy influence of the United Kingdom, Hong Kong shares the same research interests as the British and other advanced countries (Dore et al., 1996). South Korea and Taiwan have a growing interest in clinical medicine, while Thailand's emphasis is on molecular biology. Increasingly, Thailand has been collaborating with Sweden in all biological sciences (Okubo et al., 1998).

Figure 3.3: Patterns Of Co-authorship in Asia

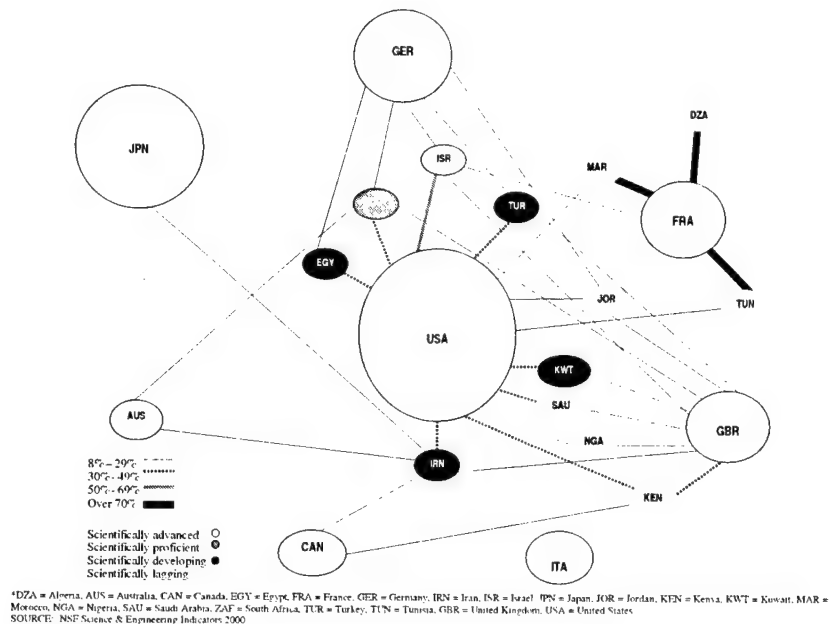


Middle East and Africa

As shown in Figure 3.4, scientifically advanced countries have a high number of collaborations with scientifically lagging countries in the Middle East and Africa region. Of the four regional figures, Figure 3.4 includes the highest number of SAC-SLC country linkages. The United States has co-authorships with 12 countries within this region. Of those, Egypt, South Africa, Turkey, Kuwait, Saudi Arabia, Kenya, and Iran have 30 percent to 49 percent of their co-authorship with the United States. The high number of SAC-SLC linkages can be attributed to the presence of pockets of excellence connected largely to particular social and natural conditions within this region. Israel, a new scientifically advanced country, has 50 percent to 69 percent of its co-authorships with the United States. It also has 8 percent to 29 percent of them with Germany, France, and the United Kingdom. As is the case with South Korea and Taiwan, Israel has not begun to collaborate heavily with the scientifically proficient, developing, and lagging countries, rather it co-authors papers mainly with other advanced countries. The high number of collaborations between the United Kingdom and the countries of this region is also evidence of Britain's continuing interaction with its former colonies. Due to a francophone influence, Algeria, Tunisia, and Morocco each have over 70 percent of their collaborations with France.

Within Africa, these countries stand out for their scientific capabilities: South Africa, Algeria and Egypt, which together make up a continental center of capacity in animal and plant research. In addition, each country has additional areas of specialization—South Africa in life science, Nigeria in agriculture and Egypt in the chemical sciences. Of these, South Africa publishes in the widest variety of disciplines, partly explaining its status as the single scientifically proficient country in Africa. The greatest interest in the Middle East is in the geosciences, due to their rich natural resources and oil (Dore et al., 1996). Finally, Algeria, Tunisia, and Morocco are increasing their collaborative research in chemistry with other countries (Okubo et al., 1992).

Figure 3.4: Patterns of International Co-authorship in the Middle East and Africa



Latin America

Figure 3.5 shows that the United States has developed strong ties with the Latin American countries. Argentina, Venezuela, Brazil, Mexico, Chile, and Colombia have 30 percent to 49 percent of their collaborations with the United States. In addition, the U.S. collaborates extensively with a seventh country—Cuba—with 8 to 29 percent of its papers. France follows with six linkages, the United Kingdom with four, and Germany with three. Of the four regional diagrams, this figure shows the least number of scientifically advanced countries collaborating with a region. Although Spain is not a scientifically advanced country, we have included it here because of its strong relationships with Latin America. Spain's strongest collaboration efforts are with Cuba, but it also has linkages with all of the countries in the figure except for Brazil. History and the commonality of language appear to have influenced the collaborations between Spain and Latin America.

Brazil and Mexico are collaborating with advanced countries in biology and biomedicine. In addition, Latin America has many mutual linkages that are illustrated in Figure 3.9. For example, Brazil and Argentina share several co-authorships. Brazil, Mexico, Argentina, and Venezuela have scientific infrastructures that increase their competitive edge and attract collaboration.

Chile has linkages with many countries due to its geography, which proves to be good for astrophysics and earth and space science in general (Okubo et al., 1992).

Figure 3.5: Patterns of Co-authorship in Latin America

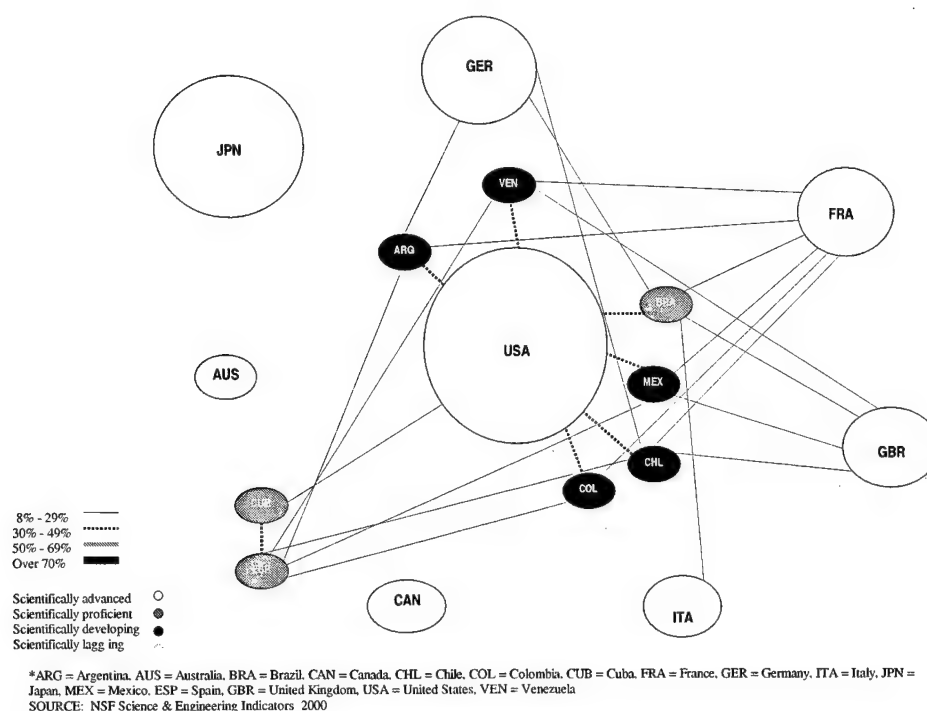


Table 3.2: The Relationship between the Number of Scientifically Lagging Countries in a Region and the Number of Collaborative Linkages

Region	Average Number of Linkages with Advanced Country	Number of Lagging Countries
CIS and Balkans	5	0
Latin America	4	0
Asia	3	3
Middle East & Africa	2.5	7

Scientific Capacity and Collaborative Links

Advanced Country Connections with Proficient and Developing Countries

As shown in Figures 3.6 and 3.7, there are large numbers of collaborations between scientifically advanced countries with proficient and developing countries. With a few exceptions,¹⁷ most of the proficient and developing countries listed in the S&T composite index have linkages of greater than 8 percent of papers published with at least one advanced country. SPCs and SDCs tend to have less developed scientific infrastructures than SACs. Consequently, they have a propensity towards seeking international collaboration with scientifically advanced countries (Luukkonen et al., 1992).

International scientific organizations play important roles in stimulating cooperation between advanced countries with proficient and developing countries. For example, European Consortium for Nuclear Research (CERN) and Institute Laue-Langevin (ILL) both play important roles in promoting collaboration and uniting European countries. In these types of organizations, all of the advanced member countries have high levels of productivity in science. Thus, proficient and developing countries are capable of benefiting from international collaboration (Okubo et al., 1992).

A close look at Figure 3.6 shows that the scientifically advanced countries have numerous co-authorships with the scientifically proficient countries. The United States has the highest number of co-authorships, followed closely by Germany and France. There are a total of 105 linkages between proficient and advanced countries, with each proficient country collaborating with an average of five advanced countries.

¹⁷ These countries are, in descending order of S&T capacity index, Luxembourg, Azerbaijan, Moldova, Macedonia, Mauritius, Benin, Costa Rica, Bolivia, Mongolia, and Turkmenistan.

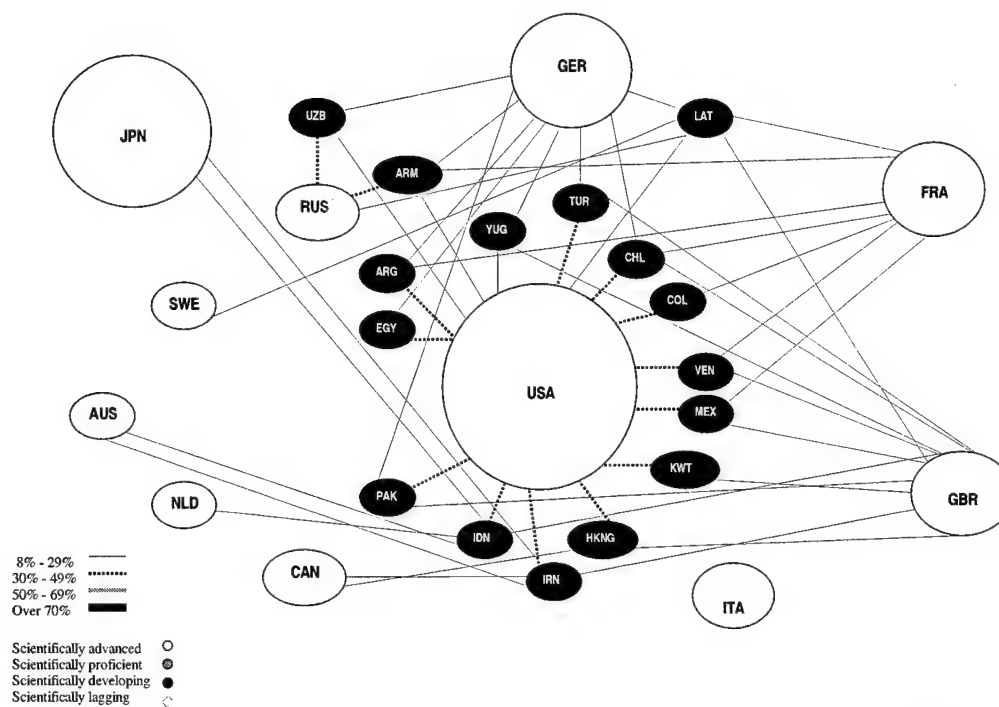
Figure 3.6: Patterns of Co-authorship Between Scientifically Advanced and Proficient Countries



As shown in Figure 3.7, the number of linkages between scientifically developing and advanced countries is 53, significantly lower than the 105 linkages between scientifically advanced and proficient countries. A scientifically developing country has an average of 3.3 linkages with advanced countries. The United States has the highest number of linkages at 16, and for 12 of those countries between one-third and one-half of their publications are published jointly with a U.S. scientist.¹⁸ Following behind the United States for the number of linkages is the United Kingdom with 11, Germany with nine, and France with seven.

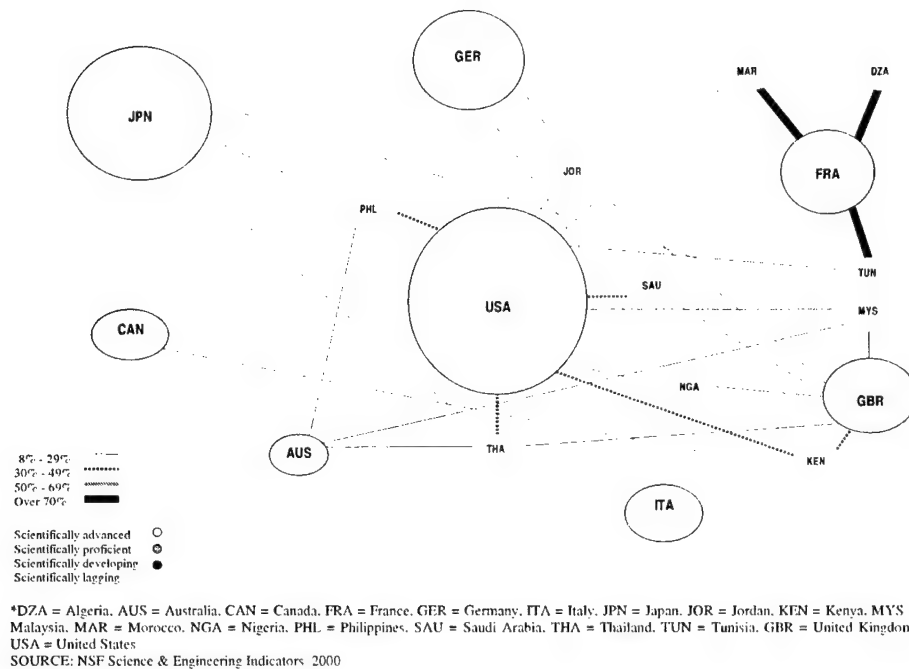
¹⁸ These are Turkey, Chile, Colombia, Venezuela, Mexico, Kuwait, Hong Kong, Iran, Indonesia, Pakistan, Egypt, and Argentina.

Figure 3.7: Patterns of Co-authorship between Scientifically Advanced and Developing Countries



*ARG = Argentina, ARM = Armenia, AUS = Australia, CAN = Canada, CHL = Chile, COL = Colombia, EGY = Egypt, FRA = France, GER = Germany, HKNG = Hong Kong, IDN = Indonesia, IRN = Iran, ITA = Italy, JPN = Japan, KWT = Kuwait, LAT = Latvia, MEX = Mexico, NLD = The Netherlands, PAK = Pakistan, RUS = Russia, SWE = Sweden, TUR = Turkey, GBR = United Kingdom, USA = United States, UZB = Uzbekistan, VEN = Venezuela, YUG = Yugoslavia
SOURCE: NSF Science & Engineering Indicators 2000

Figure 3.8: Patterns of Co-authorship Between SACs and SLCs



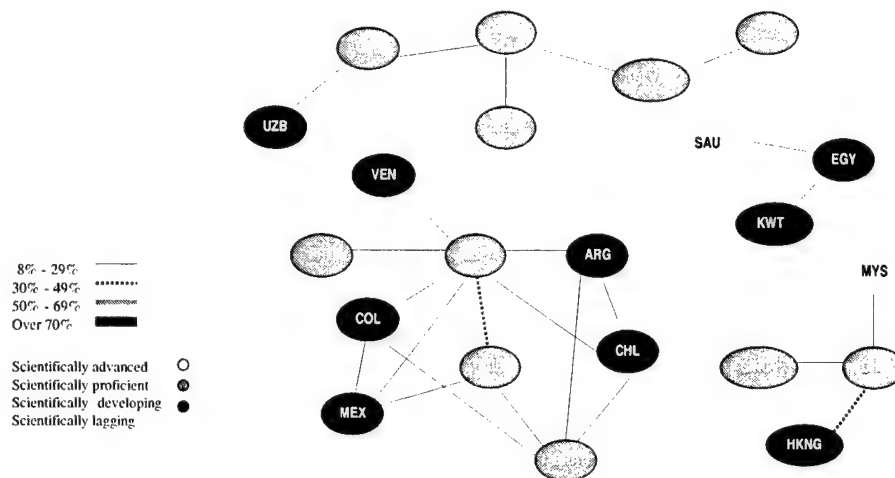
In Figure 3.8, it is clear that the number of SAC-SLC linkages (at 27) is far below all other categories of linkages. The United States has the highest number of co-author nations at nine, with four of them representing between one-third and one-half of the collaborating country's total publications. The United Kingdom follows the U.S. with six linkages with scientifically lagging countries, several of which are former colonies. Similarly, France has strong linkages with Algeria, Morocco, and Tunisia, (over 70 percent co-authorships each) which are former French territories and francophone countries. Although there are additional collaborations between SACs and SLCs, because the extent of co-authorship falls below the threshold defined for these figures (see Figure 3.1), they are not illustrated in the diagram. Analysis is hampered because data on SLCs is limited to a very small number of collaborations.

As science becomes more specialized, research areas become more narrowly focused. This reduces the chance that scientists from SLCs will find colleagues in their own country with similar interests. To pursue their scientific work, they must try to find partners in the SACs who are willing to collaborate (Luukkonen et al., 1992). Although SLCs are often invited to participate in international medical research, the dominant activity for most scientifically lagging countries is agriculture (Okubo et al., 1992). SLCs may also have a natural resource that attracts advanced countries to collaborate with them (see discussion in Section 4).

Linkages Between Proficient and Developing Countries

Although not at the same level of scientific capacity, scientifically proficient and scientifically developing countries have similar needs and interests that can promote collaboration. Figure 3.9 illustrates the linkages between scientifically proficient and developing countries. Saudi Arabia and Malaysia (lagging countries) were also included because the percentages of co-authorship observed were significant enough to justify their inclusion. A pattern emerges from this figure showing that geographic proximity may be a significant factor in facilitating collaborations. In addition, commonality of language is clearly important as exemplified by Spain's high volume of co-authorship with the Latin American countries.

Figure 3.9: Patterns of Co-authorship between Proficient, Developing, and Lagging Countries



Trends in Publication Patterns

In our effort to characterize the evolution of collaborations over time, we compared the 1995-97 co-authorship data with the data from 1986-88. We excluded all countries from the former Soviet Union, except Russia. Changes in the extent of collaboration between a selection of scientifically advanced and proficient nations are included in Table 3.3. In the table, the appropriate box is marked with an "X" if the percentage co-authorship between two nations has risen above our threshold from 1986-88 to 1995-97 or an "O" if it has dropped below our threshold in this timeframe.¹⁹ Over this period, Italy has expanded the scope of its collaboration with SPCs more than any other SAC. These SPCs are Bulgaria, Poland, Portugal, Hungary, Greece, and Brazil.

¹⁹ For the purpose of this study, the threshold value corresponded to 8 percent of the country's internationally collaborative scientific papers published jointly with the other nation (see Figure 3.1.)

**Table 3.3: Increases and Decreases in Co-authorships between Advanced Countries
with Proficient, Developing, and Lagging Countries: 1986-88 to 1995-97**

PROFICIENT COUNTRY	ADVANCED COUNTRY										
	USA	JPN	UK	GER	FRA	CAN	ITA	AUS	RUS	NLD	SWI
Brazil							X				
Bulgaria	X				X		X		X		
China			X	X							
Cuba	X			O			O				
Greece							X				X
Hungary			X		X		X				
India					X	O					
New Zealand				X							
Poland							X		X		
Portugal							X			X	
Romania					X						
South Africa								X			
DEVELOPING COUNTRY											
Chile	X										
Colombia					X						
Egypt			O								
Hong Kong						X		O			
Iran		X						X			
Kuwait						O					
Mexico			X								

LAGGING COUNTRY											
Nigeria						O					
Philippines								X			
Saudi Arabia						O					
Tunisia	X										

* "X" denotes an increase to over the 8% threshold; "O" denotes a decrease to below the 8% threshold- from 1986-88 to 1995-97. SOURCE: NSF Science & Engineering Indicators 2000

France also increased its co-authorship with Bulgaria, India, Romania, Hungary and Colombia. Romania and France's percentage of co-authored papers made quite a significant jump from 6 to 25 percent. The percentage of co-authorships for Japan and Australia with Iran both increased from approximately one percent to over 10 percent in the past 10 years. On the other hand, Germany and Cuba's percentage of co-authored papers decreased from 28 percent to 7 percent, Italy and Cuba's percentage fell from 17 percent to 5 percent. The percentage of co-authorship decreased between Canada and India, Kuwait, Nigeria, and Saudi Arabia.

Of the 48 scientifically proficient, developing, and lagging countries illustrated in Figures 3.2 through 3.9, 19 countries have increased their percentage of co-authorships (over the threshold) with an advanced country from 1986 to 1997. Twenty-one new linkages between SPCs and SACs were formed, yet there were only six new linkages between SDCs and SACs, and only two between SLCs and SACs. Overall, there is an increase in countries doing collaborative work. The table shows that there is much opportunity to further increase co-authorships. A closer look at this table shows that co-authorships with SDCs and SLCs are not increasing rapidly. Yet, it should be noted that a number of these countries may have been classified differently in 1986-88. For example, a country considered scientifically developing in 1986 may have become proficient by 1997. Collaborations in 1986 may have been a factor in pushing a country from scientifically lagging to scientifically developing or from developing to proficient in 1997.

Motivations for Collaboration Go Beyond Scientific Compatibility and Complementarity

Social factors are important influences on the collaborative networks among countries. Patterns are observed among countries in their scientific levels, socio-cultural factors and the number of scientists in the country that meet the international standards. Moreover, patterns may be related to the level of national competencies to understand and use the knowledge acquired through international research (Okubo et al., 1992). Collaborative patterns of individual countries also point to intellectual dependence. For example, one country might become an intellectual center with others dependent upon it to varying degrees (Luukkonen et al., 1992).

Factors influencing the willingness of countries to collaborate include the following:

- a) **Geographic Proximity.** Neighboring countries often have similar publication profiles. Eastern European countries provide an example of a well-defined cluster that collaborates intensively within the group. Figure 3.2 shows the intense collaborative activities of the Commonwealth of Independent States with Russia and other SACs. Figure 3.9 also shows a high degree of collaboration among the SPCs and SDCs in this region as well as other regions of the world. Another example is Australia and New Zealand which collaborate with each other eight times more than statistically expected, demonstrating a high degree of mutual dependence.
- b) **History.** A number of historical events and relationships can influence patterns of international collaboration. Among these are international security alliances and concerns, economic ties, cultural interactions, and former colonial relationships (as seen in Figure 3.4 between the U.K. and its former colonies). The impact which such forces can have on the structure of a nation's scientific community and patterns of co-publication can be long-lasting.
- c) **Common Language.** In Figures 3.4 and 3.5, several cooperative linkages between countries sharing a common language are evident. Particularly obvious examples are among the French- and Spanish-speaking nations.
- d) **Specific Problems and Issues.** Problems may arise that bring countries together to explore common scientific problems such as a natural disaster mitigation or disease control. Clinical medicine and

biomedicine provide many opportunities for scientifically developing and lagging countries to collaborate with the advanced countries. As the perceived urgency of a problem increases, the amount of collaboration increases. African countries, for example, are inclined to collaborate in clinical medicine, while Asian and Latin American countries are focused more on biology and biomedicine (Okubo et al., 1992).

- e) **Economic Factors.** International co-authorship can arise as much from economic as from intellectual linkages, particularly in cases where large-scale equipment is needed to conduct research. Analysis has suggested that the amount of co-authorship is a direct reflection of the economic value accorded to each field by society (Price, 1986). Differences in co-authorship from field to field can also be due in part to funding or the lack of it (Luukkonen et al., 1992).
- f) **Expertise.** Collaborations can be driven by the need for the best, or most appropriate expertise to pursue the objectives of the scientific query. Many developing countries have institutions and individuals with world-class expertise.
- g) **Research equipment, databases, and laboratories.** The presence of particular research equipment, databases, and laboratories in a country can give rise to international collaboration. The creation of these research tools and facilities may be the result of national policy to foster world-class expertise (basically, "you built them, they'll come"), or the outcome of diplomacy, promoting international relations through science (e.g. the CERN, the European Consortium for Nuclear Research, and bilateral nuclear research programs between Russia and the U.S.)

Movements of People

Useful data that sheds light on collaboration can be found in the National Science Board Indicators report on the movements of people. As scientists from all parts of the world travel to scientifically advanced countries to study and work. This is particularly true of scientists from developing and lagging countries. Yet, not all of these scientists are choosing to reside permanently in the advanced countries. Many work for a period of time and then return to their country of origin. Scientists from proficient countries are more likely to return home; scientists from lagging countries are least likely to return home. If they do stay in the advanced countries, scientists often retain ties with the universities and research

laboratories in their countries of origin, often using collaboration as a means to help their home country (NSB, 2000).

In all fields, the number of foreign doctoral recipients from U.S. universities who planned to stay in the United States increased steadily from 1990 to 1997. Nevertheless, in several key cases, Mexico, Brazil, and South Korea, the percentage of foreign doctoral recipients who were working in the United States in 1992-93 in science and engineering decreased by 1997. One possible explanation is that these scientists have returned home to work in their country of origin. There has been an accompanying and significant overall increase in scientific publications between the 1980s and 1990s by these countries: South Korea, 84 percent increase, Brazil, 49 percent increase, and Mexico, 49 percent increase, specifically in engineering and technology articles. The scientists may be returning to their home country because the scientific capacity has increased, giving them more and new opportunities to work in their country of origin. This is an interesting phenomenon that is worth further exploration (NSB, 2000).

Conversations with scientists, detailed more fully in the next section, highlighted several aspects of personal contact for training as both benefits and outcomes of international collaboration. Among these is the importance of face-to-face meetings for scientists, but especially for young scientists, in encouraging sharing of research findings. A number of U.S.-based researchers with whom we spoke reported hosting graduate students from developing countries, with the explicit goal of engendering training that would aid the country of origin.

Limitations of this Approach

Bibliometric data likely understates the level of international collaborative research. Scientists report that there are collaborations that do not result in co-authored papers. Moreover, there are collaborations in scientifically advanced countries involving scientists from developing countries that do not list the home country of the collaborator; this is particularly true when the developing country collaborator is living for an extended period of time in the advanced country. Despite these drawbacks, publication patterns are a strong indicator of the international scientific linkages.

A major debate in using this type of data is in determining how much work an individual author contributed to a co-authored paper. Credit is assigned to the countries involved either by whole counting or fractional counting methods. The whole counting method assigns full credit to each co-author involved. The fractional counting method assigns a fractional credit to each author so that the

total sum is 100 percent. Comparison of the results of both methods sometimes leads to contradictory results. Another problem with bibliometrics is that in most cases it is based on data from the Institute for Scientific Information, which surveys only 10 percent of all the journals in the world and favors English language publications over those in other languages. This could bias some of the patterns observed.

Collaboration Is Building Capacity – Results of Conversations with Scientists

Although indicators provide useful insights, conversations with scientists who actually participate in collaborations added a richness and texture to our understanding. While not a formal survey, the results of discussions with over one hundred scientists gives another useful perspective as to whether collaborations are building capacity. Principle findings that emerged from conversations with scientists are:

- U.S.-based scientists, a number of whom were originally from developing countries, report overwhelmingly that collaboration is building capacity in developing countries;
- Respondents report that collaboration has enabled developing country counterparts to increase their ability to do independent and research in the subject of investigation;
- The majority of scientists report that projects were initiated jointly by both the United States and the foreign counterpart;
- U.S. researchers were motivated to enter into international collaborations because their developing country counterparts had the expertise needed to shed light on the subject of research;
- S&T capacity building does not automatically result from international collaboration, according to our respondents; and
- In many places, we were told, conditions for sustained and long-term improvement in science capacity are not mature or secure.

Methodology

To better understand how international collaboration contributes to capacity building in developing countries, a set of discussions was conducted over the summer of 2000. A total of 400 collaborative research projects in a full range of scientific and technical disciplines, and their principal investigators (PIs) was identified using RaDiUS, a database of federally-funded R&D activities in the United States developed by RAND. The majority of these projects began in the

mid- to late 1990s and many are still in progress. Of these, RAND selected projects and initiated discussions with one hundred U.S.-based researchers working with developing countries. The largest number of interviews discussed collaborations between researchers in U.S. and Russia (19), followed by Egypt (13), Turkey (13), Argentina (12), India (11), China (11), Korea (10) and several others.

The discussions focused primarily on three areas: (1) reasons for collaboration, (2) how information was exchanged and (3) whether capacity growth has occurred in the developing country over the course of the collaboration. Respondents were also asked to offer additional comments on their collaborative experience, such as challenges encountered, opinions about funding and institutional support, and recommendation for improvement.

The following sections report on the major findings as they relate to international S&T collaboration. A list of all the questions and summary of responses can be found in Appendix B. Due to legal and resource constraints, interviews could not be conducted with overseas researchers involved in these collaborations to gain their perspective on the quality and impacts of the working relationship. Addressing this shortcoming in future studies would produce a more comprehensive evaluation of the benefits of international collaboration.

Collaboration is Building Capacity

Did international S&T collaboration contribute positively towards capacity building in developing countries? An overwhelming majority of respondents observed that there has been an increase in S&T capacity during their scientific collaboration. International S&T collaboration is by and large a bottom-up process, with individual scientists choosing to work with each other because of shared curiosities. Thus, this capacity development has occurred, for the most part, at the level of the individual scientists rather than across a field of study or in an organization. The most often cited gains for individual scientists include the acquisition of new knowledge and skills, greater English proficiency to facilitate international research collaboration activities, publication of research papers, and broadening of professional networks. Most of the projects we asked about were stand-alone activities and few collaborative research grants provided funding for equipment purchase or facility improvement.

Respondents said that their projects contributed to capacity building in several ways, including direct transfer of knowledge about scientific experimentation and methodology. In addition, they reported that capacity was built through

seminars and other activities with faculty, researchers and graduate students in developing countries. Many U.S.-based scientists said they made deliberate efforts to speak to students in developing countries because they considered this a channel for more rapid transfer of knowledge and technology. A few respondents said their activities had a direct effect on broadening or restructuring graduate programs at the institutions of their developing country partners.

The capacity built, when centered on an institution, was generally at a university. Of the 100 projects in this survey, 60 percent involved developing country principal investigators based in universities and another 35 percent were affiliated with government research institutes or laboratories.

In some instances where capacity growth has occurred, the increase was dramatic. For example, in one project in Turkmenistan, local researchers who were hired initially to provide logistical support for a geodynamic study (local transportation and locating sites) became real partners in research. These Turkmenistan researchers learned how to use global positioning survey (GPS) instrumentation. Combining this new skill with their superior local knowledge of geological conditions, these Turkmenistan researchers became more effective in collecting data than the U.S. researchers. Seeing this new capacity and how it could benefit the research project, the U.S. scientists donated GPS equipment and computers to these Turkmenistan researchers, turning them into their primary data collection crew and later including them in all aspects of the analytic phase.

Collaboration is Building Independent Capacity

The great majority of respondents stated that international collaboration has enabled developing country researchers to conduct independent and advanced research. Within the context of this study, "independent and advanced research" refers to capacity to conduct international level research without assistance from other countries. The figure may be somewhat misleading: many respondents emphasized that while *expertise* to conduct independent and advanced research was present, appropriate equipment and facilities as well as sufficient funding to support research and experiments were often absent.

In a small number of cases, respondents said that researchers in developing countries possessed capacity to conduct independent and advanced research *prior* to collaboration rather than as a result of international links. In many developing countries, world-class expertise can be found in individuals or small pockets of excellence, e.g., a national research laboratory or a university research team. Deliberate government policies are often crucial when significant

resources are necessary to develop such capacity. Where resource input is less intensive, individual effort may make a difference. Overall, respondents said that collaboration has the positive effect of augmenting this capacity to do independent and advanced research.

For those who did not observe the development of sufficient capacity to conduct independent and advanced research, the reasons cited were either that S&T capacity was too low at the start of collaborations to be raised to international levels in the time available, or other prerequisites for independent and advanced research (e.g., a well-defined and enforced legal and regulatory framework) were absent. In spite of this, several respondents indicated that their collaborators were nonetheless "moving in the right direction."

Nature of Research Affects Motivations for Collaboration

Most U.S.-based researchers queried for this study did not start out to build capacity; they were seeking to do excellent science. The ability to generate scientific knowledge is greatest when all the participants in the collaboration have something to bring to the effort. One might generalize that this "interaction among peers" is most likely accomplished when the collaborators are from countries that are comparable in their level of scientific development. (This echoes the bibliometric results that advanced countries are more likely to collaborate with other advanced nations and the level of cooperative work falls off with countries at lower levels of capacity.) Such a generalization suggests that there is a tension between the scientific goals of collaboration and the goal of S&T capacity building. The more comparable the level of scientific capacity, the less need there is for intentional capacity building effort.

The comments of our respondents, especially those who had worked in scientifically developing and lagging countries, reflected this apparent trade-off. Those who did not view their collaborators as equals mentioned that the foreign scientists required "more patience" to work with than a scientist from an advanced country. Several respondents also mentioned that these kinds of international efforts required a longer time for the research work to bear fruit, that one had to "be committed to international collaboration in the long haul to produce results." This long commitment was also associated with a significant time investment on the part of the U.S. scientist to solve the particular problems associated with international activities. These included logistical concerns, communication difficulties, and institutional weaknesses. Several respondents noted the lack of support from their own institutions for international S&T

collaboration. Some reported inability to get approval from department heads and university administrators for overseas research visits. Others said that their institutions find management of research grants for international collaboration troublesome. A small number of respondents also indicated that, in order to make international collaboration an option, they changed the nature of their research project to either make it appropriate for local resources or provide ways which local talent could be more readily included.

The points included in the previous paragraph represent real scientific costs that may be associated with the decision of a scientist in an advanced country to collaborate with scientists from a less advanced nation. Given the presence of these costs, it is relevant to ask why these scientists chose to collaborate. In answering this question, scientific fields and projects split themselves into two categories: those that require international collaboration (collaboration is a scientific imperative) and those that do not (collaboration is an added benefit). In our discussions, these groups were of approximately equal size; slightly less than half the respondents indicated that their projects would have been possible even without foreign collaboration.

Collaboration as a Scientific Imperative

The first category of fields and projects—those that have a scientific imperative to collaborate—are characterized by a number of factors. The first are those fields and projects that require access to local sites or resources for study. In the words of one respondent, “you can’t get Chinese plants except in China.” This “local resource dependence” is also clear in fields such as archaeology and geology where the objects of study are generally large and immobile. Work may also depend on other “appropriate” local conditions, some of which may be institutional or infrastructural. Projects in environmental sciences, for example, can depend on certain types or levels of pollution to test theories or make measurements. In some countries, either explicit or *de facto* government policy may require cooperation with a national to gain access to these types of local resources. A tabulation of this natural resource intensity for all the fields in the survey is included in Table 4.1.

Table 4.1: Percentage of Respondents Mentioning Local "Natural" Resources as Important for Research Collaboration

Field:	Total Number of Respondents:	Percent Mentioning Local Resources:
Archaeology	2	100
Paleontology	2	100
Geology/Earth Sciences	11	100
Environmental Science	4	100
Oceanography	1	100
Botany	4	100
Zoology	2	100
Biology	13	85
Engineering (all fields)	14	7
Energy Technology	4	25
Nuclear Technology	2	0
Materials Science	17	6
Chemistry	9	11
Physics	9	0
Computer Science	5	0
Mathematics	2	0

Although we worked from a small sample, the table contains few surprises. Researchers in zoology would be much more likely to seek out a particular natural environment than physics researchers. It should be noted that these "resource requirements" do not exclude or devalue additional reasons for

collaboration such as expertise (see below.) Beyond questions about the resources available in countries for scientific research, a number of respondents also indicated that their specific research project required international collaboration because appropriate collaborators were only available outside the United States. In these instances, the presence of local experts acts as the same kind of magnet as a desirable natural resource bringing the attention of, in this case, U.S.-based scientists.

In some cases, it was easier for U.S. scientists to find partners interested in a particular research problem overseas than in the United States. For example, one U.S.-based researcher reported that it has become increasingly difficult to find U.S.-based collaborators in the field of mechanical engineering. Since information technology and computing science are knowledge areas pushing growth in the U.S. economy, fewer resources and researchers in the U.S. are devoted to mechanical engineering. In contrast, mechanical engineering receives substantial government support in developing economies like Korea and Turkey. These places become key targets for collaboration.

Sometimes U.S.-based researchers choose to work with researchers from a scientifically developing or lagging country because the latter represented the leading international experts on the research subject. Often, this expertise was acquired as a result of recent graduate training in the U.S. For one U.S. researcher, a Turkish scientist was an attractive partner because his U.S. graduate training had brought him to the forefront of his field. Moreover, a considerable Turkish government grant allowed him to acquire the latest equipment. In this case, knowledge was transferred back to the U.S.-based researcher; he could not have conducted this research without collaboration. In other cases, the expertise is more rooted in a local knowledge base that has developed over time and that is less dependent on equipment and facilities, e.g., mathematics and other theoretical or conceptual sciences.

Collaboration as an Added Benefit

The scientists with whom we spoke cited expertise as a central reason for collaborating whether or not international collaboration was necessary or a chosen option for their particular project. In all but a single field, 50 percent or more of the respondents cited expertise as a reason for collaboration. (See Table 4.2 below) The presence of needed facilities or equipment was cited much less often. In only two fields (with very few respondents) did even half of the researchers cite these two reasons and in six of the 16 fields neither was cited at

all. The fields that named facilities or equipment as key to spurring collaboration were experimental sciences such as physics, chemistry, biology, and engineering.

Table 4.2: Percentages of Respondents in a Field Citing Expertise, Facilities, or Equipment as a Reason for Collaboration

Field (Responses):	Expertise:	Facilities:	Equipment:
Archaeology (2)	0	0	0
Paleontology (2)	50	0	0
Geology/Earth Sciences (11)	73	9	18
Environmental Science (4)	75	0	25
Oceanography (1)	100	0	0
Botany (4)	50	25	0
Zoology (2)	50	0	0
Biology (13)	85	23	31
Engineering, all fields (14)	79	14	29
Energy Technology (4)	100	50	50
Nuclear Technology (2)	100	50	50
Materials Science (17)	82	18	24
Chemistry (9)	89	22	33
Physics (9)	78	33	33
Computer Science (5)	100	0	0
Mathematics (2)	100	0	0

When the reasons for collaboration are analyzed based on whether the interaction is between U.S. scientists and researchers in scientifically advanced,

proficient, developing and lagging nations, the variation that is observed follows expected trends (see Table 4.3).

Table 4.3: Motivation for Collaboration Cited (by Country Type of the Collaborating Nation)

	Percentage of Respondents Citing:		
Country Type:	Expertise:	Facilities:	Equipment:
Advanced	93	26	33
Proficient	75	21	25
Developing	74	17	19
Lagging	71	0	29

Although the percentage of U.S. scientists in our survey seeking expertise, facilities and equipment through collaboration is highest when collaborating with advanced countries, all three of these reasons are still important for most of the remainder of the world. Even in scientifically lagging countries or in countries sought out for a particular natural or locational resource, expertise of varied types is still a draw for collaboration.

Perceived Costs and Benefits

The vast majority of scientists with whom we spoke stated that significant benefits came from most, if not all, collaborative efforts. Statements of affirmation such as "two plus two can equal five" marked the comments of a number of scientists. Scientists engaged in "voluntary" collaboration cited several other reasons for seeking partners: (1) expanding their scientific network, (2) gaining information about what was going on in their field internationally, (3) gaining access to potential student recruits, and (4) providing enriching or educational experiences for their current students. Overall, the overwhelming

majority of the respondents said that collaboration has benefited them and their institutions.²⁰ (See Table 4.4)

Table 4.4: Did the Collaboration Increase the Scientific Capacity of your U.S. Institution? (by Country Type of Collaboration)

		PERCENTAGE OF RESPONDENTS ANSWERING:	
Country Type in Collaboration: [Examples]	Number of Responses:	Yes:	No:
Advanced [Russia, Korea]	27	93	7
Proficient [China, India]	23	83	17
Developing [Argentina, Egypt, Turkey]	42	83	17
Lagging [Thailand, Kenya, Malaysia]	7	43	57

When viewed as a whole, collaboration is seen as most beneficial to the U.S. institution when it occurs with other advanced nations, although significant benefits were seen for collaborations with all nations. However, many respondents saw other benefits to collaboration that are not connected to the particular scientific project. Several researchers in the survey consciously approached international collaboration as a way to participate in the transfer of know-how and technology to developing countries. Scientists who said this generally had experience working in the developing country or were originally from that developing country. For example, one respondent believed that collaboration with researchers in Korea, together with his classes and seminars

²⁰ These benefits included, in order of the frequency of their mention, learning new techniques and broadening understandings, access to samples or data, broadening their scientific network, and gaining a 'global view' of research problems.

for Korean faculty and graduate students, had hastened the transfer of knowledge in one area of information technology that was practically absent in Korea. Since he was originally from Korea and has actively maintained contacts there, he was able to identify appropriate research partners and knew how to communicate effectively in that social and cultural setting. The collaboration thus enabled not only creation of new research capacity, but also the training of Korean faculty and graduate students.

Initiation of Activities is Often Mutual

Almost half of the respondents said that both parties played a role in conceiving and designing the collaborative research. Overall, U.S. researchers were more often responsible for writing and submitting research proposals. Several respondents noted that their international counterparts did not have sufficient knowledge or skill (e.g., English proficiency) to write the proposals. A large majority of survey respondents indicated that future collaborations are planned or in the works.

Descriptions by respondents on how research collaborations were initiated also graphically illustrate the importance of potential collaborators having met before beginning cooperative work. A large number of respondents cited personal visits, fellowships, previous research experience, or an already existing relationship as the precursor for their collaborative research projects examined in the survey. This value was relatively constant (U.S.-SAC, 63%; U.S.-SPC, 75%; U.S.-SDC, 73%; and US-SLC, 71%) even across collaborations between the U.S. and nations of different science capacity levels.

When projects are examined by motivation for collaboration, the importance of personal interaction in establishing "voluntary" scientific relationships is stronger. More than four out of five projects where collaboration was a voluntary option noted the importance of pre-existing relationships, compared to three out of five projects where international collaboration was a scientific imperative. Those fields that do not deem collaborations as essential may therefore require mechanisms to enable international exchange before collaborations are initiated.

Frustrations of Collaborating

From the perspective of the U.S.-based scientists with whom we spoke, the process of international scientific collaboration could be a varied experience. Although there were respondents who indicated that their interactions had gone

smoothly and encountered no bureaucratic or political barriers, others pointed out frustrations or hindrances to cooperation and progress in research. The following were the most frequently cited by respondents:

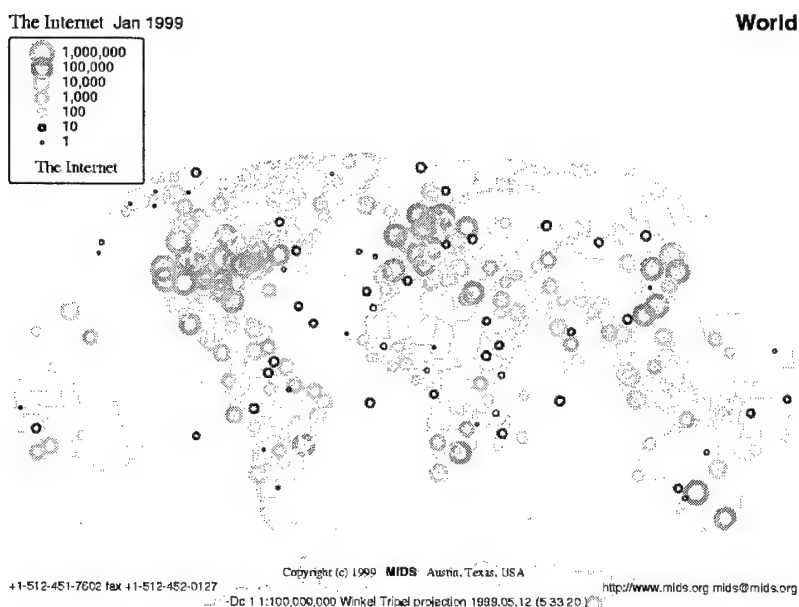
- **Bureaucratic hurdles and delays.** The extensive amount of time required in preparing and following up grant applications. Delays were associated with both the administrative systems in the US *and* in the collaborating countries;
- **Lack of flexibility in spending.** Several researchers reported frustration with rigid requirements on the spending of grant money;
- **Lack of institutional support.** Several researchers reported that they find little support for international collaboration from their U.S. institutions;
- **Legal and regulatory obstacles.** There are frustrations created by legal and regulatory requirements obtaining visas, for example, for transferring equipment and research materials;
- **Lack of a common language.** The lack of proficiency in a common language, which today is usually English, among foreign researchers and graduate students can slow progress in research; and
- **Spillover effects of international diplomacy.** Conflicts in international relations can present significant frustrations for scientists.

The Role of Information and Communications Technology

The Internet has become the central mechanism for communication and information exchange, according to the scientists with whom we spoke. Personal visits are also very important and increasingly common, but day-to-day communications take place across information and communications networks. Over three-fourths of the respondents reported using the Internet for electronic mail, transfer of data files and other digital documents to aid collaboration. The proliferation of Internet access in developing countries has significantly helped to cut cost and time in communication and information exchange. Telephone calls, facsimile transfers and postal and courier services have become secondary, used only when necessary because of limited bandwidth, lack of software or hardware, or absence of Internet access.

Scientifically developing and even lagging countries are increasingly linked to the Internet. Figure 4.1 shows the extent of Internet access worldwide and dramatically illustrates that many, if not most, countries with some aspirations to be players in the world scientific scene have access to the Internet and the World Wide Web.

Figure 4.1: Internet Access for Different Parts of the World



Although many respondents said that the Internet has revolutionized communication and information exchange in international collaborations, they also stressed its limitations as well.

- First, the majority felt that the Internet does not substitute for interaction in person to discuss ideas or work on experiments. Some emphasized that personal interaction helps to build mutual trust and confidence, which are critical to forming collaborations and making them successful.
- Second, personal interaction is key to many capacity building activities that require the learning of physical skills, e.g., in conducting surveys and experiments. Knowledge in this case is implicitly transferred through first-hand observation and emulation. The Internet cannot substitute for face-to-face interactions, even when using videoconferencing.

- Third, the Internet cannot currently fully address the serious need for reference materials in developing countries.

Limitations of this Approach

One clear limitation of this set of interviews is that it is restricted to research collaborations between U.S.-researchers and their counterparts in developing countries over the last decade. Nonetheless, the results of these interviews offer a useful representation of the state of international science and technology cooperation and its impact on S&T capacity building in developing countries: the United States can stand-in as the proxy for the scientifically advanced world. In addition, the U.S. has a long history of S&T cooperation with developing countries around the world.

Three caveats are necessary for the projects identified and the responses gathered in this part of the inquiry. First, international S&T cooperation and government support do not occur in a vacuum. History, economic relations, security considerations, political concerns and humanitarian goals in addition to intellectual curiosity are among the numerous factors that influence the direction and amount of government support for international research collaboration. These in turn can affect choices individual researchers make about the specific topics of inquiry and partners in cooperative research.

In the case of the United States, close research ties have always existed with countries in Asia and Central and South America. (In comparison, European countries have closer research ties with former colonies in Africa and the Caribbean.) Furthermore, "diplomacy through science" was the rationale behind a great number of collaborative research projects between U.S. and Soviet scientists. Collaborative research on nuclear technology, for example, allowed the two countries to mutually assess capabilities, gathering critical information to support bilateral and multilateral arms control talks. The collapse of communism in the Soviet Union and Eastern Europe opened new opportunities for research collaboration. U.S. scientists visited areas previously prohibited to Western researchers, collecting data and conducting experiments that were impossible to conduct during the Cold War years.

A second caveat is that responses from U.S.-based researchers were assessments based on their experience in working with researchers from developing countries. No attempt was made to consult with the developing country researchers involved in these collaborative enterprises.

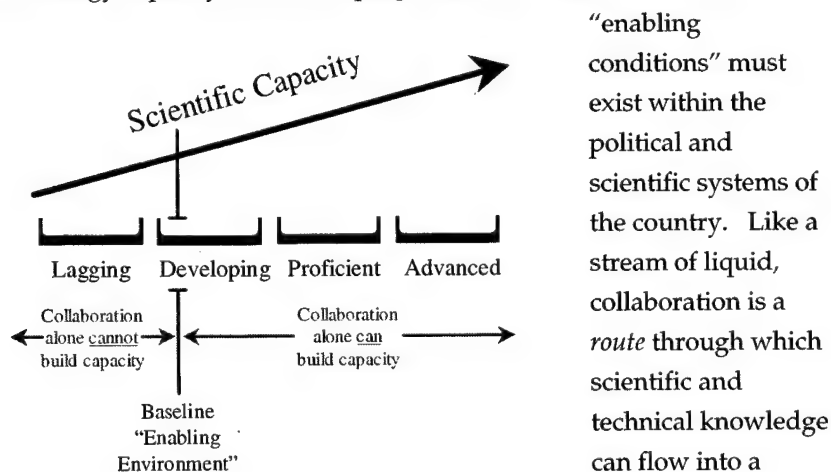
Finally, the number of responses on collaboration between U.S.-based researchers and their international counterparts in this survey was not directly proportionate to the actual number of cooperative research projects between the U.S. and these foreign countries. This is because the RaDiUS database covers *only* federally funded R&D research activities in the U.S. and responses depended on the willingness and availability of the U.S.-based researcher to participate in this survey. Nevertheless, the U.S. government is the largest funding source for international research collaboration and the number of responses, with few exceptions, broadly correlates to the total number for each developing country identified in the RaDiUS database.

Increasing the Effectiveness of Future Efforts

Scientific collaboration is having a positive impact on the ability of developing countries to participate in world science. Economic growth and social welfare may also be benefiting as a result of these activities. However, it is clear that this chain of events works best when some enabling conditions are in place at the start of scientific collaboration. This means that S&T collaboration as a model for capacity building and economic growth may have only a limited usefulness to the poorest countries.

Several findings have particular significance for policy and for those concerned with finding ways to increase the well-being of people in need of the products of science and technology. These are summarized in the following ten points.

- *Successful collaborations work from the bottom-up, are peer-reviewed, and result from shared interests.* Scientists with whom we spoke reported that they collaborated because of the expertise of their foreign collaborator, not because of their country of origin. In most advanced countries, the allocation of R&D funds is heavily influenced by committees of scientists. This strengthens the system and ensures relevance. Allowing scientists to choose areas of collaboration will help ensure that the best science is being done.
- *Collaboration is most successful when there is a basic level of capacity in place.* Before international collaboration can have a beneficial effect on the science and technology capacity of a developing nation, it is clear that certain



country from international sources. If the country lacks the ability to absorb that knowledge and put it to good use, its potential positive and lasting effects will simply drain away. Taking advantage of the flow requires institutions and resources to create an absorptive capacity that will allow the country to make the knowledge and technology its own and put it to its own uses. In the case of scientific research, this requirement constitutes a "baseline" level of scientific infrastructure to make collaboration an effective mode of capacity building. Nations having capacity below this baseline level cannot measurably use collaboration to build capacity. Above the baseline, collaboration becomes a viable (if not completely sufficient) mechanism for augmenting capacity. This distinction is schematized in the adjacent figure.

- The required "baseline" level of capacity is not fixed and likely differs among countries, fields of study, and even among specific research problems within fields. The required baseline capacity may be lower for research projects away from the forefront of international science but possibly quite relevant to the needs of a developing nation. Types of scientific activities and the things being studied will affect the level of capacity needed to get started. This could be

Motivating Factor	Scientific Method		
	Observational	Experimental	Theoretical
Expertise			
Global Problem			
Equipment Sharing			

thought of as the matrix shown here. It may be easiest to initiate

collaboration in observational sciences around a global problem than any of the other types of collaboration.

- Information and communications technology can be enormously helpful, but it does not in itself motivate or enable collaboration. It is one of several factors and tools that can be used, and access to ICT can be very helpful. Building ICT in specific countries where collaboration looks like it will have a beneficial effect may be a way to streamline future capacity building. Other efforts would be needed in conjunction, however, to build additional enabling factors such as laboratories, availability of state-of-the-art data and textbooks, and other key features of successful collaboration.

- *Collaboration usually requires face-to-face meetings in order to initiate and negotiate the relationship.* This factor was reported to us by the vast majority of the scientists with whom we spoke. Holding conferences and enabling scientists from developing countries to travel and meet with peers may be one of the most important ways to facilitate collaboration.
- *Common language and shared knowledge are crucial to successful collaboration.* Where a common language is not available, trained translators may be one option that can be explored to help facilitate sharing of information. Shared knowledge results from access to the same scientific publications and materials. For example, a common database, either on paper or available electronically, could jumpstart collaborations.
- *Sustainability of capacity building activities in developing countries is sometimes fragile.* Conditions for sustainability range across many of the inputs to science that we have described in this report, but clearly a stream of reliable funding is one of the most important. Perhaps a supplemental grant or accompanying measure to peer-reviewed science being sponsored by advanced countries and conducted with developing countries would help to ensure on-going activities. In addition, studies show that efforts which are more relevant to the development goals of the nation are more likely to be sustained. When a research question is relevant to national goals, it is more likely to obtain political and material support from the developing country. Thus, taking into consideration the development goals of nations—as individual countries and groupings—and the resources available to them would better ensure that capacity building efforts will endure and have lasting effects.
- *Measures of outputs and outcomes are needed in order to track and monitor the effectiveness of collaboration and must be built in from the start.* Quantitative and qualitative measures should be explored in more detail so that they can be built into collaborations at the start which, along with appropriate feedback mechanisms, can enable funders and participants to see what works well in producing both good science and scientific capacity.
- *Policies addressing “brain drain” must take a more complex reality into account.* The decision of an individual scientist to reside abroad cannot be seen as a total loss for a developing country. In many cases, collaboration between an advanced and a developing country is initiated by a researcher originally from a developing nation. The motivations for these collaborations can be professional and personal. Methods to seed these expatriate initiated collaborations may be a highly effective means to develop capacity.

- *The presence of a few passionate leaders and/or champions can positively affect the success of international S&T collaboration.* Since scientific research could take years to produce useful results, the presence of such individuals is critical to initiating new research and sustaining on-going ones. They can also play an important role in training a new generation of scientists and serving as the human link across projects and institutions.

Future areas of study

Further study of S&T capacity building is necessary to provide a more complete picture, including, but not limited to the following areas:

- Additional data collection for further refinement of the S&T Capacity Index;
- Sensitivity type analysis of the data used for the S&T capacity Index;
- Bibliometrical analysis done in both absolute and relative terms;
- Micro-level bibliometrical analysis between the U.S. and a small number of developing countries; and
- Bibliometrical analysis that shows the importance of the SLCs, SDCs, and SPCs for the SACs.

**Appendix A: Data supporting the
Composite S&T capacity index**

Index of Science and Technology Capacity

Country	Weighting Factors										INDEX																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
	GDP per Capita	Scientists and Engineers per Million Population	S & T journal articles	Expenditures for R & D (% of GDP)	Institutions and Universities per Million Population	Adjusted Metric for Students Studying in USA	GDP per Capita	Scientists and Engineers per Million Population	S & T journal articles	Expenditures for R & D (% of GDP)		Institutions and Universities per Million Population	Patent (USPTO and EPO)	Adjusted Metric for Students Studying in USA																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																														
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United States	29240	3676	173233	2.6	63.65	315766	42198	2.42	2.20	13.15	2.72	5.72	11.13	0.20	0.55	2.19	0.68	0.46	0.93	5.03	3.08	2.12	2.08	2.00	1.97	1.05	0.78	1.73	1.14	1.60	1.60	1.53	1.48	1.49	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48	1.48</

Scientifically Developing Nations										Scientifically Lagging Nations											
Iran	1560	560	286	0.5	0.39	2	345	-0.46	-0.21	-0.20	-0.07	-0.38	-0.15	-0.41	-0.04	-0.05	-0.03	-0.02	-0.03	-0.03	-0.22
Berlin	300	176		0.7	0.34	0	103	-0.59	-0.51	-0.22	0.21	-0.39	-0.15	-0.45	-0.05	-0.13	-0.04	0.05	-0.03	-0.01	-0.04
Yugoslavia, FR	1374	1099	487		1.79	13	1136	0.83	-0.21	-0.19	-0.70	-0.25	-0.15	-0.29	-0.04	0.05	-0.03	-0.17	-0.02	-0.01	-0.02
Kuwait	13076	230	171	0.2	2.63	21	1056	0.51	-0.47	-0.21	-0.49	-0.17	-0.15	-0.31	-0.07	-0.12	-0.03	-0.17	-0.01	-0.01	-0.25
Hong Kong, China	23660	0	1743		1.49	1174	53	1.84	-0.64	-0.09	-0.70	-0.28	-0.11	-0.46	0.15	-0.16	-0.01	-0.17	-0.02	-0.01	-0.03
Costa Rica	2770	532		0.2	4.00	23	1000	-0.34	-0.23	-0.22	-0.42	-0.03	-0.15	-0.31	-0.03	-0.06	-0.04	-0.11	0.00	-0.01	-0.27
Bolivia	1010	172		0.5	2.15	2	580	-0.52	-0.51	-0.22	-0.05	-0.21	-0.15	-0.38	-0.04	-0.13	-0.04	-0.11	-0.02	-0.01	-0.03
Egypt, Arab Rep.	1290	459	1192	0.2	0.64	51	2037	-0.49	-0.29	-0.13	-0.41	-0.35	-0.15	-0.16	-0.04	-0.07	-0.02	-0.10	-0.03	-0.01	-0.28
Mongolia	380	910			3.45	0	726	0.59	0.06	-0.22	-0.70	-0.09	-0.15	-0.36	-0.05	0.02	-0.04	-0.17	-0.01	-0.01	-0.29
Turkmenistan	582	0	168	0.6	1.28	0	168	0.57	-0.84	-0.22	0.08	-0.30	-0.15	-0.44	-0.05	-0.16	-0.04	0.02	-0.02	-0.01	-0.03
Indonesia	640	182	282	0.1	0.31	37	11077	0.56	-0.80	-0.20	0.60	-0.39	-0.15	1.20	-0.05	-0.13	0.03	0.15	-0.03	0.01	-0.30
Malaysia	3570	93	327	0.2	0.30	122	4760	-0.25	-0.57	-0.20	-0.38	-0.33	-0.15	0.25	-0.02	-0.14	-0.03	-0.10	-0.03	-0.01	0.02
Uganda	310	21	326	0.6	0.24	0	326	-0.60	-0.63	-0.22	0.04	-0.40	-0.15	-0.42	-0.05	-0.16	-0.04	0.01	-0.03	-0.01	-0.31
Thailand	2160	103	332	0.1	0.90	73	7549	-0.40	-0.96	-0.20	-0.53	-0.33	-0.15	0.67	-0.03	-0.14	-0.03	-0.13	-0.03	-0.01	-0.32
Kyrgyz Republic	380	584		0.2	0.64	4	2107	-0.59	-0.81	-0.22	-0.44	-0.42	-0.15	-0.41	-0.05	-0.05	-0.04	-0.11	-0.03	-0.01	-0.33
United Arab Emirates	17970	0		0.3	0.37	4	2107	1.24	-0.64	-0.22	-0.70	-0.38	-0.15	-0.15	0.10	-0.16	-0.04	-0.17	-0.03	-0.01	-0.33
Togo	330	98		0.5	0.67	1	97	-0.60	-0.57	-0.22	-0.07	-0.35	-0.15	-0.45	-0.05	-0.14	-0.04	-0.02	-0.03	-0.01	-0.33
Tajikistan	370	666		0.1	0.98	0	164	-0.59	-0.13	-0.22	-0.59	-0.32	-0.15	-0.44	-0.05	-0.03	-0.04	-0.09	-0.03	-0.01	-0.34
Jordan	1150	94	157	0.3	1.35	8	807	0.51	-0.57	-0.21	-0.36	0.00	-0.15	0.34	0.04	0.04	0.09	0.00	0.01	-0.03	0.35
Tunisia	2060	125	158	0.3	1.51	1	252	-0.41	-0.95	-0.21	-0.31	-0.27	-0.15	-0.43	-0.03	-0.14	-0.04	-0.08	-0.02	-0.01	-0.35
Philippines	1090	157	142	0.2	0.63	68	1486	-0.52	-0.52	-0.21	-0.41	-0.36	-0.15	-0.24	0.04	-0.13	-0.04	-0.10	-0.03	-0.01	-0.37
Uruguay	6070	0		0.2	3.64	11	319	0.00	-0.94	-0.22	-0.50	-0.07	-0.15	-0.31	0.00	-0.16	-0.04	-0.13	-0.01	-0.01	-0.38
Kazakhstan	1340	0		0.3	0.71	3	1024	-0.49	-0.54	-0.22	-0.38	-0.35	-0.15	-0.31	-0.04	-0.16	-0.04	-0.07	-0.03	-0.01	-0.38
Gabon	4170	234		0.0	5.00	0	95	-0.19	-0.46	-0.22	-0.70	0.06	-0.15	-0.45	-0.02	-0.12	-0.04	-0.17	0.01	-0.01	-0.39
Saudi Arabia	6310	0	660		0.53	41	3848	0.09	-0.54	-0.17	-0.70	-0.37	-0.15	0.12	-0.16	-0.03	-0.12	-0.03	-0.01	-0.01	-0.39
Sri Lanka	810	191		0.2	0.64	4	656	-0.54	-0.50	-0.22	-0.45	-0.36	-0.15	-0.37	-0.05	-0.12	-0.04	-0.12	-0.03	-0.01	-0.39
Nepal	210	40		0.3	0.22	0	1041	-0.61	-0.81	-0.22	-0.33	-0.40	-0.15	-0.31	-0.05	-0.15	-0.04	-0.08	-0.03	-0.01	-0.40
Burundi	140	33		0.3	0.15	0	42	-0.61	-0.82	-0.22	-0.28	-0.40	-0.15	-0.46	-0.05	-0.15	-0.04	-0.07	-0.03	-0.01	-0.40
Guatemala	1840	104		0.2	0.83	5	774	-0.46	-0.56	-0.22	-0.49	-0.34	-0.15	-0.36	-0.04	-0.14	-0.04	-0.12	-0.03	-0.01	-0.41
Congo, Dem. Rep.	680	460			0.04	1	33	-0.56	-0.53	-0.22	-0.70	-0.42	-0.15	-0.46	-0.05	-0.07	-0.04	-0.17	-0.03	-0.01	-0.42
Iraq	10195	0			0.45	0	35	-0.44	-0.64	-0.22	-0.70	-0.38	-0.15	-0.46	0.04	-0.16	-0.04	-0.17	-0.03	-0.01	-0.42
Peru	2440	233			1.01	10	1154	-0.37	-0.46	-0.22	-0.70	-0.32	-0.15	-0.29	-0.03	-0.12	-0.04	-0.17	-0.03	-0.01	-0.42
Syrian Arab Republic	1030	300	70	0.2	0.46	0	374	-0.52	-0.52	-0.22	-0.44	-0.38	-0.15	-0.41	-0.04	-0.15	-0.04	-0.11	-0.03	-0.01	-0.42
Central African Republic	300	56		0.2	0.57	0	15	-0.60	-0.80	-0.22	-0.44	-0.36	-0.15	-0.46	-0.05	-0.15	-0.04	-0.11	-0.03	-0.01	-0.43
Vietnam	350	303			0.25	2	1433	-0.59	-0.40	-0.22	-0.70	-0.40	-0.15	-0.25	-0.05	-0.10	-0.04	-0.17	-0.03	-0.01	-0.43
Ecuador	1530	146		0.0	1.31	11	1805	-0.47	-0.53	-0.22	-0.67	-0.29	-0.15	-0.19	-0.04	-0.13	-0.04	-0.17	-0.02	-0.01	-0.43
Panama	2940	0		0.1	1.07	1	904	-0.32	-0.64	-0.22	-0.57	-0.32	-0.15	-0.33	-0.03	-0.16	-0.04	-0.14	-0.03	-0.01	-0.43
Georgia	970	0		0.1	3.33	1	538	-0.53	-0.64	-0.22	-0.57	-0.10	-0.15	-0.30	-0.04	-0.16	-0.04	-0.14	-0.01	-0.01	-0.44
Burkina Faso	240	17		0.2	0.28	0	70	-0.60	-0.63	-0.22	-0.45	-0.39	-0.15	-0.45	-0.05	-0.16	-0.04	-0.11	-0.03	-0.01	-0.44
Guinea	530	265			1.27	0	261	-0.57	-0.44	-0.22	-0.70	-0.30	-0.15	-0.43	-0.05	-0.11	-0.04	-0.17	-0.02	-0.01	-0.44
Madagascar	260	12		0.2	0.27	1	91	-0.60	-0.63	-0.22	-0.46	-0.39	-0.15	-0.45	-0.05	-0.16	-0.04	-0.12	-0.03	-0.01	-0.44
Guinea-Bissau	160	0			7.50	0	25	-0.61	-0.54	-0.22	-0.70	-0.30	-0.15	-0.46	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.45
Oman	5946	0			0.43	0	482	-0.01	-0.54	-0.22	-0.70	-0.38	-0.15	-0.30	-0.04	-0.16	-0.04	-0.17	-0.03	-0.01	-0.45
Botswana	3070	0			3.75	0	265	-0.31	-0.64	-0.22	-0.70	-0.05	-0.15	-0.42	-0.03	-0.16	-0.04	-0.17	0.00	-0.01	-0.45
Jamaica	1740	0			3.08	0	1524	-0.45	-0.64	-0.22	-0.70	-0.12	-0.15	-0.23	-0.04	-0.16	-0.04	-0.17	-0.01	-0.01	-0.45
Lebanon	3500	0	80		1.67	6	785	-0.35	-0.64	-0.22	-0.70	-0.26	-0.15	-0.35	-0.02	-0.16	-0.04	-0.17	-0.02	-0.01	-0.46
Nigeria	300	15	401	0.1	0.22	4	899	-0.60	-0.63	-0.19	-0.69	-0.40	-0.15	-0.33	-0.05	-0.16	-0.03	-0.14	-0.03	-0.01	-0.46
Lithuania	5020	0			0.00	0	5	-0.01	-0.64	-0.22	-0.70	-0.42	-0.15	-0.46	0.00	-0.16	-0.04	-0.17	-0.03	-0.01	-0.46
Trinidad Tobago	4520	0			0.00	0	838	-0.16	-0.64	-0.22	-0.70	-0.42	-0.15	-0.34	-0.01	-0.16	-0.04	-0.17	-0.03	-0.01	-0.46
Kenya	350	0	258		1.02	4	2780	-0.59	-0.54	-0.20	-0.70	-0.32	-0.15	-0.05	-0.05	-0.16	-0.03	-0.17	-0.03	-0.01	-0.46
Nicaragua	370	204			0.21	1	369	-0.59	-0.49	-0.22	-0.70	-0.49	-0.15	-0.41	-0.05	-0.12	-0.04	-0.17	-0.03	-0.01	-0.46
Bangladesh	350	52	141	0.0	0.21	0	825	-0.59	-0.80	-0.21	-0.66	-0.40	-0.15	-0.34	-0.05	-0.15	-0.04	-0.16	-0.03	-0.01	-0.47
Zimbabwe	620	0			2.91	1	573	-0.56	-0.64	-0.22	-0.70	-0.14	-0.15	-0.38	-0.05	-0.16	-0.04	-0.17	-0.01	-0.01	-0.47
Namibia	1940	0			1.76	0	137	-0.43	-0.64	-0.22	-0.70	-0.25	-0.15	-0.44	-0.04	-0.16	-0.04	-0.17	-0.02	-0.01	-0.48
Senegal	530	3		0.0	1.89	0	559	-0.58	-0.64	-0.22	-0.68	-0.24	-0.15	-0.38	-0.05	-0.16	-0.04	-0.17	-0.02	-0.01	-0.48
Dominican Republic	1770	0			0.43	3	763	-0.44	-0.64	-0.22	-0.70	-0.37	-0.15	-0.35	-0.04	-0.16	-0.04	-0.17	-0.03	-0.01	-0.48
El Salvador	1860	20			0.43	2	568	-0.44	-0.64	-0.22	-0.70	-0.37	-0.15	-0.41	0.04	-0.16	-0.04	-0.17	-0.03	-0.01	-0.48
Rwanda	230	35		0.0	0.62	0	87	-0.61	-0.62	-0.22	-0.64	-0.36	-0.15	-0.45	-0.05	-0.15	-0.04	-0.16	-0.03	-0.01	-0.48
Morocco	1240	0	244		0.32	4	889	-0.50	-0.64	-0.20	-0.70	-0.39	-0.15	-0.33	-0.04	-0.16	-0.03	-0.17	-0.03	-0.01	-0.48
Papua New Guinea	890	0			1.96	0	59	-0.54	-0.64	-0.22	-0.70	-0.40	-0.15	-0.46	-0.04	-0.16	-0.04	-0.17	-0.02	-0.01	-0.49
Paraguay	1760	0			0.19	1	431	-0.45	-0.64	-0.22	-0.70	-0.40	-0.15	-0.34	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.49
Ghana	390	0			0.97	1	823	-0.59	-0.64	-0.22	-0.70	-0.33	-0.15	-0.34	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.49
Zambia	330	0			1.86	0	284	-0.60	-0.64	-0.22	-0.70	-0.24	-0.15	-0.42	-0.05	-0.16	-0.04	-0.17	-0.02	-0.01	-0.49
Malawi	210	0			2.00	0	193	-0.61	-0.64	-0.22	-0.70	-0.23	-0.15	-0.44	-0.05	-0.16	-0.04	-0.17	-0.02	-0.01	-0.49
Honduras	740	0</																			

Scientifically Lagging Nations																									
Haiti	410	0	0.26	2	363	-0.59	-0.64	-0.22	-0.70	-0.39	-0.16	-0.43	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.03	-0.50					
Congo, Rep.	110	0	0.71	1	197	-0.62	-0.64	-0.22	-0.70	-0.35	-0.15	-0.43	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.50					
Ethiopia	100	0	0.33	0	401	-0.62	-0.64	-0.22	-0.70	-0.39	-0.15	-0.40	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.03	-0.50					
Malawi	250	0	0.57	0	143	-0.60	-0.64	-0.22	-0.70	-0.38	-0.15	-0.44	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.50					
Mauritania	410	0	0.40	0	58	-0.59	-0.64	-0.22	-0.70	-0.38	-0.15	-0.46	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.50					
Angola	360	0	0.08	0	231	-0.59	-0.64	-0.22	-0.70	-0.41	-0.15	-0.43	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.50					
Sudan	290	0	0.14	0	219	-0.60	-0.64	-0.22	-0.70	-0.41	-0.15	-0.43	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.50					
Yemen	260	0	0.00	0	306	-0.60	-0.64	-0.22	-0.70	-0.42	-0.15	-0.42	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.03	-0.50					
Sierra Leon	140	0	0.41	0	76	-0.61	-0.64	-0.22	-0.70	-0.38	-0.15	-0.45	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Niger	200	0	0.30	0	46	-0.61	-0.64	-0.22	-0.70	-0.39	-0.15	-0.46	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Cambodia	260	0	0.09	0	130	-0.60	-0.64	-0.22	-0.70	-0.41	-0.15	-0.44	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Myanmar	282	0	0.02	1	150	-0.60	-0.64	-0.22	-0.70	-0.42	-0.15	-0.44	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Mozambique	210	0	0.18	0	99	-0.61	-0.64	-0.22	-0.70	-0.40	-0.15	-0.45	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Korea, Dem. Rep.	430	0	0.00	0	32	-0.58	-0.64	-0.22	-0.70	-0.42	-0.15	-0.46	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Lao PDR	320	0	0.00	0	75	-0.60	-0.64	-0.22	-0.70	-0.42	-0.15	-0.45	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Chad	230	0	0.00	0	46	-0.61	-0.64	-0.22	-0.70	-0.42	-0.15	-0.46	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					
Eritrea	200	0	0.00	0	44	-0.61	-0.64	-0.22	-0.70	-0.42	-0.15	-0.46	-0.05	-0.16	-0.04	-0.17	-0.03	-0.01	-0.04	-0.51					

(A) Gross national product per capita for 1998 [World Bank, World Development Indicators, 2000. http://www.worldbank.org/data/wdi2000/pdfs/tab1_1.pdf] Data from other sources, including United Nations Statistics [<http://www.un.org/Depts/unsd/socialinc-eco.htm>], are indicated in italics.

(B) Number of scientists and engineers in R&D per 1 million population [World Bank, World Development Indicators 2000. http://www.worldbank.org/data/wdi2000/pdfs/tab5_12.pdf] Additional data obtained from the "Second European Report on Science and Technology Indicators" S-59, December 1997, EUR 17639 and the 1998 World Science Report, UNESCO, Paris., in all cases the most recent data accessible was used. Values from these additional sources are indicated in italics.

(C) Number of science and technology journal articles published in 1995-1997 average values [Science Indicators 2000, National Science Foundation]. Additional values (indicated in italics) were obtained from "Second European Report on Science and Technology Indicators" S-59, December 1997, EUR 17639 and are measures for 1995 article publications.

(D) Expenditures on R&D as a percentage of the GNP, data for the latest year available 1987-1997 [World Bank, World Development Indicators 2000. http://www.worldbank.org/data/wdi2000/pdfs/tab5_12.pdf] Additional data (indicated in italics) obtained from varied sources including the 1998 World Science Report and are for the most recent year accessible.

(E) The number of scientific research institutions (universities, institutes, etc.) per million population [Research Centers and Services Directories, The Gale Group, <http://galenet.gale.com/taacp/db/rscsd> and World Bank, World Development Indicators 2000, http://www.worldbank.org/data/wdi2000/pdfs/tab2_1.pdf]

(F) Total number of US patents filed 1997-1999 and EPO Patents filed 1992-1994 by Citizens of the Country (most recent years available) ["Patent Counts by Country/State and Year, All Patents, All Types, Jan 1, 1977-Dec 31, 1999" USPTO, DOC, March 2000 and "Second European Report on Science and Technology Indicators" S-59, December 1997, EUR 17639]

(G) Total Number of US F-1 and J-1 Student Visas issued minus 3/4 the number of student visas converted to US permanent resident status in 1998 [US State Department Internet Site, Data for FY 1997, <http://travel.state.gov/1997niv.pdf> and US Immigration and Naturalization Service Statistical Yearbook 1998, <http://www.ins.gov/graphics/aboutins/statistics/fmm98.pdf>] Canadian number from parliamentary debate on the subject (1998) since visa numbers do not correctly reflect student exchange between the two countries.

(H) Values from the corresponding column (A through G) converted to a comparative index by determining the number of standard deviations which the value of the national characteristic is away from the international average in that characteristic. Positive values indicate that the nation's value exceeds the international average.

(I) Weighted values of the scaled index parameters (seven columns labeled H) using the weighting factors at the top of the column to generate each factor's contribution to the overall scientific capacity index.

(J) Overall Index of Scientific Capacity - calculated as a sum of the weighted factor values (seven columns labeled I)

Values indicated in reduced boldface came from a number of unofficial Internet sources and should, at best, be considered educated estimates.

* indicates OECD member states

Appendix B: Report on Interviews with Scientists

A. Introduction and methodology

To better understand how international collaboration contributes to capacity building in developing countries, a survey was conducted between July 17 and August 11, 2000. A total of 400 collaborative research projects in a full range of scientific and technical disciplines, and their principal investigators (PIs) in the U.S. were identified using RaDiUS (Research and Development in the United States), a RAND database on all federally funded science and technology-related research and development (R&D) activities in the United States. The majority of these 400 projects began in the mid- to late 1990s and many are still in progress. Out of these, more than 100 interviews were conducted with their U.S.-based principal investigators (PIs). These surveys covered collaborative research projects involving researchers from 21 countries outside of the United States. The greatest number of interviews was on collaborations between researchers in the United States and Russia (19), followed by Egypt and Turkey (13 each), Argentina (12), India and China (11 each), Korea (10), and several others.

The interviews focused primarily on three areas: (1) reasons for collaboration, (2) whether capacity growth had occurred in the developing country (individual, institutional or country-wide in that field of study or area of research) during the collaboration and (3) how information was exchanged. Respondents were also asked to offer additional comments on their collaborative experience, such as challenges encountered and opinions about how to improve science and technology (S&T) collaboration between developed and developing countries.

One clear limitation of this survey is that it is restricted to S&T collaborations between U.S.-researchers and their counterparts in developing countries over the last decade. Nonetheless, the results of these interviews offer a useful representation of the state of international science and technology cooperation and its impact on S&T capacity building in developing countries because the United States is a scientifically advanced country with interest in a broad range of scientific research problems. In addition, the United States has a long history of S&T cooperation with developing countries around the world.

Furthermore, three caveats are necessary for the projects identified and the responses gathered in this survey. First, international S&T cooperation and government support do not occur in a vacuum. History, economic relations, security considerations, political concerns and humanitarian goals in addition to intellectual curiosity are among the numerous factors that influence the direction and amount of government support for international research collaboration. These in turn can affect choices individual researchers make about the specific topics of inquiry and partners in cooperative research. (Gaillard, 1994)

In the case of the United States, close research ties have always existed with countries in Asia and Central and South America. (In comparison, European countries have closer research ties with former colonies in Africa and the Caribbean.) In addition, "diplomacy through science" was the rationale behind a great number of collaborative research projects. Collaborative research on nuclear technology between U.S. and Soviet scientists, for example, allowed the two countries to mutually assess capabilities, gathering critical information to support bilateral and multilateral arms control talks. Security considerations also affected the level, direction and emphasis of aid for research from developed countries.

A second caveat is that is that responses from U.S.-based researchers were assessments based on their experience in working with researchers from developing countries. No attempt was made to consult with the developing country researchers involved in these collaborative enterprises.

Third, the number of responses on collaboration between U.S.-based researchers and their international counterparts in this survey was not directly proportionate to the actual number of cooperative research projects between the U.S. and these foreign countries. This is because the RaDiUS database covers *only* federally funded R&D activities in the U.S. and responses depended on the willingness and availability of the U.S.-based researcher to participate in this study. Nevertheless, the U.S. government is the largest funding source for international research collaboration in the United States and the number of responses, with few exceptions, broadly correlates to the total number for each developing country identified in the RaDiUS database.

Section B below presents the questions used in our survey. Section C summarizes responses to the three major questions in this study, that is, reasons for collaboration, whether capacity grew as a result of collaboration and how information was exchanged.

B. Survey questions

All respondents to this survey were asked to answer the following list of questions and in the order listed. Since these are open-ended questions, respondents were free to speak briefly or at length.

1. Who initiated the project? Could you briefly describe how it got started?
 - Are your foreign collaborator(s) from government institutions, universities, or the private sector?
 - Have you had previous experience working with your foreign collaborator(s) or the foreign country (countries) involved in the project?
2. Why did you chose to collaborate with this (these) foreign researchers/institutions? I'd like to offer you some possible reasons to see if one or more fits:
 - Presence of expertise/facilities/equipment in the foreign country?
 - The foreign country provides unique conditions for research? e.g. climate, ecology, human communities?
 - Common and complementary experiments and data exchange?
 - Research requires global/international partnerships?
 - Others that you could state/briefly describe?
3. Have you seen the scientific or technical capacity of your partner country (countries) grow over time?
 - If Yes, why and how? If No, why not?
4. Have your foreign collaborator(s) acquired or increased ability to independently advance research in this area as a result of this collaboration?
5. How did you exchange information with your foreign collaborator(s)?
6. Has the collaboration enhanced US (your own institution's) capacity?

7. Would this project have been possible without foreign collaboration?
8. Are future collaborations planned or decided?
9. Other comments?

C. Summary of responses.

(a) Reasons for international collaboration (Questions 1, 2, 6, 7)

U.S. researchers reported numerous reasons for scientists in developed and developing countries to enter into international collaboration. They are summarized in the nine points below. These reasons are not exclusive of each other; in fact, most respondents reported more than one reason for their respective projects.

Shared interest in the research problem was reported as a leading reason for collaboration. Interviews showed that almost half (49%) of the projects in this survey were initiated by PIs from both the United States and the foreign country (or countries) involved. The identification of a research problem and discovery of shared interest frequently grew from previous experience in working with the foreign researchers, their institutions, or countries (54% of respondents reported this). Two common avenues for interaction were encounters at professional meetings around the world and visits by the U.S. researchers to the institutions or countries of the international collaborators and/or *vice versa*.

International collaboration also stemmed from another form of personal experience. 21% of the respondents said that projects grew out of collaborative research relationships that already existed between themselves and their foreign graduate students or post-doctoral fellows while they were in the United States. The return of these foreign scientists to their home countries to pursue academic and research careers opened opportunity for new and formal international collaborative research. It should be noted that this type of relationship may be even more important than these data indicate since the interviewees were not specifically asked about post doctoral or graduate student connections between them and their foreign collaborators. Indeed, personal knowledge of the foreign PIs and/or previous experience in working with the foreign country significantly affected decisions by U.S. scientists to enter into collaborative research relationships. Many respondents indicated that previous personal experience with foreign PIs and/or their countries increases trust in building a collaborative research relationship and confidence in continuing an existing one.

78% of respondents reported that the expertise possessed by foreign PIs was a central reasons for initiating collaboration. Many fewer respondents highlighted

facilities and equipment (18% and 22% respectively) as a reason they chose to collaborate with the foreign researchers. Yet, this apparent weakness does not necessarily handicap the potential for developing countries to participate in international collaboration. Cooperation on theoretical or conceptual research problems, for example, are less driven by desire for equipment and facilities. These include fields like pure mathematics, for example, which one respondent pointed out 'sometimes only requires a pencil and paper.'

Nearly three-quarters of the respondents reported that collaboration was driven by common and complementary experiments and data exchange. This was not surprising given that relevant expertise is often available in developing countries. Collaboration was mutually beneficial in many ways. Developing countries frequently possessed raw data and specimens, which were of interest to U.S. researchers. Developing countries might also choose collaboration with developed country scientists in order to obtain technologies, equipment or ideas that would help them to turn information into useful knowledge. In some cases, dividing the work between the two sides made economic sense. Laboratory technicians might be cheaper and more readily available in developing countries, while U.S. researchers could provide developing country scientists cost-free access to equipment and technology.

On whether global/international partnerships were required for their collaborative research projects, nearly half the respondents (47%) said that partnerships were not necessary, that is, the U.S. side could have conducted the research on its own. However, many respondents said that researchers in developing countries could not have conducted the same research project without working with U.S. or other Western scientists. International collaboration allows developing country scientists to obtain research materials or technologies that they would otherwise have to purchase and often the costs were prohibitive. In some cases, the materials might not even be sold or legally transferred to them except within a collaborative research framework with Western scientists. A respondent also mentioned that the strengthening of intellectual property rights (IPR) legislation in industrialized countries has also made it more difficult for developing country scientists to obtain some research materials.

On the other hand, the utility and necessity of international partnership to U.S. researchers depended on the specific nature or characteristics of the research problem. Research problems involving certain unique conditions (e.g., geology, human communities, and fauna and flora) in the developing country encourage collaborative research. For example, U.S. researchers studying problems in seismology, geodynamics, botany and biology were motivated to collaborate

with developing country scientists in order to obtain assistance in doing field work, access information and materials and benefit from local knowledge. Research problems of a transboundary or global nature also encourage international partnerships. Marine resource conservation and climate change are two examples.

Personal or professional interest in helping developing countries to build capacity and assist individual researchers to conduct scientific inquiries. In several cases, respondents came from these developing countries. They considered collaboration as a quicker way to transfer the latest in scientific knowledge and technical know-how to their country of origin or former institutions of academic or professional affiliation.

In the case of Russia, many respondents who worked with Russian researchers considered collaboration as financial and moral support to keep Russian science alive. Funding from the Russian government has been drastically reduced in the past decade as a result of national economic decline. Many U.S. researchers interviewed expressed professional concern about the deterioration of human resources and physical infrastructure for science in Russia.

The situation in Russia appeared to sharply contrast with that in China and Turkey. Many respondents who were involved in collaborative research in these two countries expressed optimism for S&T capacity building there. They considered the high-level political support and increased government funds for science in these countries critical to sustain local S&T capacity building and to increase public awareness of connections between S&T capacity and national economic development.

In several cases, U.S. researchers were motivated to enter into international collaborations because the developing country PIs in the project were among the best in the world in the subject of query or the most appropriate professional match for that particular research problem. For example, one respondent reported that India has many world-class mathematicians. Another said that it was difficult for him to find collaborators to do mechanical engineering studies in the United States. Information technology and biochemistry breakthroughs drive the present U.S. economy. As a result, research support and student enrollment have substantially declined in this field of study. He said he could more easily find research partners and hire technicians in industrializing countries like Korea and Turkey, whose governments and industries still see value in mechanical engineering.

Expanding international professional networks and introducing themselves (and their graduate students) to other perspectives, cultures and approaches to

scientific inquiry were also important motivations for U.S.-based researchers. In fact, networking was a frequently reported benefit for the U.S. side in international collaboration. Other benefits included learning, access to samples or data, and gaining a 'global view' of their research field. Two respondents, in particular, said they believe the experience will help them in future interactions with graduate students and researchers from those developing countries.

Finally, some respondents considered international S&T collaboration a kind of humanitarian effort or diplomatic instrument to improve the image of the United States in developing countries.

In summary, a variety reasons motivated U.S.-based researchers to participate in collaborative research with scientists in developing countries. While the majority of respondents reported that international collaboration brought little concrete benefit to their own research or enhanced the S&T capacities of their institutions and the United States, all respondents considered international collaboration as worthwhile and useful to bridging S&T capacity gaps between developed and developing countries.

*(b) Building capacity through international S&T collaboration: successes and limitations
(Questions 3 and 4)*

The great majority of respondents (88%) reported that scientific or technical capacity was increased in the developing country during the collaboration. The most common kinds of increased capacity observed were the acquisition of new knowledge and skills by developing country researchers (and their graduate students who participated in the projects) and single and/or co-authored publications in professional journals in developing countries or the West. In some cases, collaboration helped to highlight a research problem and enable developing country researchers to obtain research support from their own governments or international organizations. However, improvements or expansion in equipment and facilities did not generally occur and any change was usually minor because few sources of support for international collaborations provided funds for equipment purchase or facility upgrade.

On whether collaboration itself had enabled their developing country counterparts to acquire or increase ability to do independent and advance research in the particular subject of investigation, the vast majority (80%) answered in the affirmative. However, several emphasized that the developing country researchers had this ability even prior to collaboration (e.g., Russian nuclear scientists who are world-class caliber). Many also added that the lack or shortage of funds, equipment and facility were significant impediments to enabling independent and advance research in developing countries.

Indeed, S&T capacity building does not automatically result from international collaboration. A few respondents questioned the relevance of knowledge created or S&T capacity built as a result of international collaboration to the development needs of the partner countries. One respondent said in particular that he knew developing country scientists who would pick research problems that have more appeal to international partners (especially funders) than any real value to their own country. Developing country scientists might also be motivated to participate in international collaboration with Western researchers in order to raise their status and influence in domestic science and policy circles. Investigating a research problem is of secondary interest to them.

Of the 100 projects in this survey, 60 percent involved developing country PIs based in universities and another 34 percent were affiliated with government research institutes or laboratories. Since private markets are poorly developed in developing countries and enabling legislation are generally absent, developing country researchers are not generally motivated to find applications for their discoveries. This inability to generate economic or humanitarian benefits from their research to national development may negatively impact their efforts to secure support for their own research projects—or for S&T capacity building activities on the whole—from their own governments or populations.

Researchers could also suffer in a personal way when they are unable to connect their research with domestic needs. Since salaries for professors and researchers in developing countries are usually quite low, economic reasons sometimes compel researchers to switch to other professions (e.g., in Russia, scientists become taxi drivers and street vendors) or move to Western and oil-rich Arab countries (the latter more common to scientists in Pakistan) to continue their careers. A few respondents said that international collaboration could hasten brain drain by exposing developing country scientists to superior work and living conditions overseas and helping them to identify employment opportunities abroad.

Finally, in developing countries where application of scientific knowledge and technology are strongly emphasized in government policy and supported by industry (e.g., Korea and Turkey), a few respondents reported concern about sustaining long-term capacity in basic research. Several respondents stressed that simultaneous and complementary capacity building in basic and applied S&T is necessary.

In summary, international collaboration has enabled some level of S&T capacity building in most developing countries but the conditions for sustained and long-term improvement are not mature or secure.

(c) *Communication and information exchange (Question 5)*

Visits to the U.S. by developing country PIs and *vice versa* were reported by an overwhelming number of respondents (90%) in this survey. This was not surprising considering the majority of projects covered in this survey were funded by the U.S. National Science Foundation's international exchange program, whose funds are primarily for international exchange visits.

Nearly half (43%) of the respondents reported giving lectures or seminars to graduate students and faculty in their collaborator's institution overseas.²¹ They considered this an efficient way to transfer and disseminate new knowledge to developing countries, producing a direct impact on capacity building. Developing country scientists and graduate students could apply the new knowledge to their work and pass it to others through teaching at graduate and undergraduate levels. Some respondents also hosted developing country graduate students and post-doctoral fellows who are involved in the collaboration in their laboratories or universities in the United States. These visits can last from two weeks to several months.

In terms of information technology, the Internet has become the central mechanism for communication and information exchange. Over three-fourth of the respondents (76%) reported using the Internet for electronic mail and the transfer of data files or other digital documents. The proliferation of Internet access in developing countries has significantly helped to cut cost and time in communication and information exchange. Telephone calls, facsimile transfers and postal and courier services have become secondary, used only when necessary due to limited bandwidth, lack of software or hardware, or absence of Internet access.

Although many respondents said that the Internet has revolutionized communication and information exchange in international collaborations, they also stressed its limitations. First, the majority felt that the Internet does not substitute interaction in person to discuss ideas or work on experiments. Some further emphasized that personal interaction helps to build mutual trust and confidence, which are critical to forming collaborations and making them successful. As indicated above on reasons for collaboration, most collaborative research resulted from meetings or other forms of personal interaction between collaborators. Second, personal interaction is key to many capacity building activities that require the learning of physical skills, e.g., in conducting surveys

²¹ The actual number of lectures and teaching activities is likely higher since this was not the specific topic of the question.

and experiments. Knowledge in this case is implicitly transferred through first-hand observation and emulation. The Internet cannot sufficiently enable an equal level of intimacy in interaction even with the use video conferencing or other technological aids. Third, the Internet cannot fully address the serious need for reference materials in developing countries.

*(d) Recommendations to improve capacity building through international collaboration
(Questions 8 and 9)*

Data and studies show that the number and range of topics in research collaborations between researchers in developed and developing countries are continuing to increase. In the survey conducted for this report, three-quarters of the respondents said that they have either decided or are making plans to continue collaboration with their research partners in developing countries.

Although obtaining funding was regarded as the most prominent challenge, respondents put forth many recommendations to improve conditions for international research collaboration and sustained S&T capacity building in developing countries. The first group of proposals and recommendations below target issues that hamper international collaboration in the United States. The second group of proposals and recommendations target hurdles to S&T capacity building in developing countries.

Recommendations for activities in the United States (or other donor countries and organizations):

Increase funding and create incentives for international collaboration. More resources are necessary. There are currently few sources dedicated to support scientific research collaboration between developed and developing countries. Government agencies and international organizations should also create incentives to make university administrators more supportive of collaborative research with developing countries. Several respondents reported difficulty in persuading their university administrators to give them time and resources to participate in research activities with developing countries.

Greater flexibility in funding and more long-term support. Support for international collaboration, e.g., funds from the National Science Foundation, is usually restricted to international transportation expenses (and some computing expenses). Respondents expressed a desire that grants allow purchases of research materials, equipment and reference materials as well as university grant administration fees and other incidental expenses. More long-term support, e.g., allowing multiple grant renewals, was also recommended. Some types of

research problems take many years to produce results. In other cases, a longer grant period helps to consolidate capacity building gains.

Increase resources for international travel and hosting exchange activities in developing countries. Travel and other funding support for researchers from developed and developing countries to attend international meetings, seminars, workshops and conferences facilitate intellectual exchange, professional network building and identification of research partners. Making available funds to hold international meetings, seminars, workshops and conferences in developing countries could also aid to increase attendance by researchers in developing countries.

Provide resources for logistical support. Making travel arrangements, such as obtaining visas, purchasing airplane tickets and making hotel reservations, were cited as time-consuming tasks. A travel office could be set up within the National Science Foundation or an outside agent (commercial or non-profit) could be selected to make travel arrangements for researchers receiving U.S. government grants. Another form of logistical support proposed was service assistance for developing country scientists when they are in the United States. These visitors need help to learn how things work in an environment that is alien to them, including housing, transportation, banking and health services. Having such assistance would help visitors to devote more time and energy to substantive research work in the United States.

Travel and stipend support for graduate students. Respondents emphasized that graduate students can bring ideas and labor to benefit a research project. Enabling graduate student participation also expands their education and helps to foster future generations of collaborators. One respondent working in a SLC mentioned the importance of providing long term educational opportunities for students that might not be qualified to enter 'traditional' US higher or graduate education. His view was that truly teaching SLC students to appreciate and love science would require a period of mentoring that could not be accomplished in short visits to the country.

Simplify bureaucratic procedures. Reducing the amount of paperwork in applying and administering a grant could reduce costs (for applicants and their universities) and encourage more U.S.-based scientists to participate in collaborative research. Some respondents said that many researchers hesitate to conduct collaborative work with developing countries because they consider that costs (especially time investment) exceed financial and professional gains.

Relax visa approvals for persons and material and equipment transfers. Some respondents indicated that visa applications for persons coming to the United

States and material and equipment transfers (in and out of U.S.) are too restrictive and take too long. Delays in approval and rejections increase costs and make productive collaborations more difficult.

Recommendations for activities in developing countries:

Improve access to information. Helping developing countries to build good reference libraries is critical. Researchers and graduate students in developing countries are often handicapped in their scientific queries because they have poor access to professional journals, textbooks and information about the research activities and grant sources overseas. Another way to address this weakness may be through the Internet. Grants could help pay for reference/information services operated via the Internet. However, this may not work in places where bandwidth is limited or without support to upgrade and expand hardware and software capabilities in developing countries.

Strengthen physical infrastructure and institutions necessary for S&T capacity building. Stable water and electricity supplies, good basic education and training, reliable and accessible telecommunications and transportation services, efficient bureaucratic processes and well-enforced laws (especially those related to intellectual property rights) and regulations are all essential to sustain long-term capacity building. International donors need to strengthen support in all these areas.

Find applications for S&T discoveries. Unlike the United States and other scientifically advanced and industrialized countries, developing countries generally do not have laws, institutions or well-developed market mechanisms to put knowledge and technologies to use in producing goods and services for domestic and international markets. Resources and programs are needed to help developing countries to identify and apply S&T discoveries. Commercial applications were stressed as especially important to help generate income for researchers and resources for investment in S&T activities.

Create an enabling environment for developing country scientists. To stem the outflow of talent from developing countries, conditions need to be created to enable scientists to conduct work they find meaningful. International exchange programs that support multiple visits by scientists from developing countries to attend meetings and conduct experiments in the United States were cited as good models. These programs enable developing country researchers to upgrade their knowledge, expand professional networks and gain access to equipment and facilities overseas without having to leave their home countries. International donors could also build shared-access laboratories or information centers

(independently or jointly with local premier institutions) in various parts of the world.

Support to publish in international journals and apply for international funding. Providing funds to assist developing country researchers to publish in international peer-reviewed journals. Such assistance may be in the form of grants for editing and proofreading services, printing, computing and other communications expenses. Although many developing country scientists publish their research findings, most do so in journals of their own institutes or other local publications. Since the circulation of these publications is limited, the work of these researchers is not widely known to the international scientific community. More international collaborations could likely occur if their work appears in international peer-reviewed journals. Another benefit of publication in international peer-reviewed journals is that it could help developing country scientists to better establish their credentials when applying for funds from international sources. In this connection, researchers in developing countries need assistance to learn how to prepare and submit grant applications to international grant makers. Many respondents in this survey emphasized a need to address this weakness, which is one of the underlying causes of asymmetrical relationships between developed and developing country researchers.

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